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FACULTY OF SOCIAL SCIENCE AND HUMANITIES
LOUGHBOROUGH DESIGN SCHOOL

Visual Communication of Technology:
Its impact on designing and innovation in industrial
and engineering design education

BY

CHENG-SIEW BEH

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

Doctor of Philosophy
of Loughborough University

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Abstract

Visual communication (VC) resources can be seen as playing an increasingly important role in delivery and learning systems in today’s design and technology education. The performance of current tools and resources is the primary concern of this research, and particularly whether they take full advantage of VC when delivering technological information to industrial design (ID) and engineering design (ED) students.

This thesis sought key principles behind the visual communication of technology (VCT) and its association to designing, creativity and innovation through a literature survey. The findings concluded that there were many such assertions made with little evidence concerning the associations suggested. Some guiding sources and key emerging principles (KEPs) for good VCT practices were established.

A miniature-kite-designing exercise was conducted as a case study for the purpose of examining the links between VCT, designing and creativity and/or innovation. Kite-technological-information posters were used as the VCT tool for the kite-designing case. A comparative study of kite-designing was conducted in Malaysia to check the reliability of the study, and another validation study was carried out for the purpose of establishing the validity of the data gathering.

Visual technological information (VTI) for kite design (or a kite-poster) was refined accordingly to the KEPs established from the literature review, and its visual impact was tested through the use of eye-tracking technology. Some selected current and historical visual tools, which have been used in design and technology communication and were recognised as having positive impacts were analysed and articulated in order to reveal a deeper understanding of the KEPs. These were further validated through eye-tracking of reading patterns of participants on those selected visuals. The perceptual responses toward those visuals were also recorded and analysed.
A theoretical research framework was established to investigate VTI representation used in books by Ashby (1999) and Ashby and Johnson (2002), in new authors’ scholarly papers (METU, 2010), and of the author’s analysis and redesign of some of those studied VTIs based on the KEPs emerging from the research. A questionnaire survey was conducted within a number of higher education institutions in 3 regions around the world in order to achieve reliable data gathering. This third case study was validated through experts’ discussion of the findings and related issues.

Within these three case studies, a mixture of ‘scientific’ (using the eye-tracker device) and conventional methods (questionnaires, interviews, discussion group and comparative studies), and also others methods such as design workshops, analysing existing resources, using ‘own practice’ of design-and-redesign activities were conducted to provide quantitative and qualitative measurements to empirically validate the literature search.

Evidence of links between VCT, designerly activities which involved knowledge, skills and values within the technological communication, and of facilitating creativity was obtained. Empirical evidence showed that VTIs were effective in communicating knowledge, skills and values; where the KEPs criteria had played essential roles in enriching the visual emphasis of VTIs. The redesigning exercise using the author’s own practice, which articulated the KEPs through the redesign of the existing VTIs for the purpose of more effective VCT, again obtained significant evidence of visual effectiveness and easy understanding capability.

Evidence from the analysis of 2 books on materials technology for ID and ED students, views from the 2 materials experts, and the literature review suggested that ID and ED students require difference types of representational models and graphical strategies of VCT in their learning. However, the empirical data from the research, which was supported by one of the materials experts, suggested that ID and ED students even with different cultural backgrounds did not require different VTIs or the use of different VCT strategies for effective communication.
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<td>ED</td>
<td>Engineering Design</td>
</tr>
<tr>
<td>KEPs</td>
<td>Key Emerging Principles</td>
</tr>
<tr>
<td>VC</td>
<td>Visual Communication</td>
</tr>
<tr>
<td>VCT</td>
<td>Visual Communication of Technology</td>
</tr>
<tr>
<td>VTI</td>
<td>Visual Technological Information</td>
</tr>
</tbody>
</table>
Chapter 1  Introduction

Chapter Overview

Chapter One provides the background of this research and reveals the author’s personal motivations for undertaking this PhD research study. It defines the purpose of this research and its foci by stating the aims, objectives and questions to be explored. The value of the research is anticipated, and overall research agenda is outlined. This chapter also includes an overview of the thesis structure to guide the readers through this work.
1.1 Research Background

1.1.1 Academic research context

There have been series of conferences concerning diagrammatic representation and inference since the year 2000. Much research relating to diagrammatic representation has been completed in the area of cognitive and computer sciences, which was related to the theory and application of diagrams; however, none of them were from the perspective of graphic design practice. Likewise, Paley (2008, p.2) believes that the areas of rich visual representation and metaphorically-driven layout are under researched due to fear and difficulty among cognitive and computer scientists.

This research study seeks to support the use of visual culture, particularly visual communication of technology (VCT) in assisting communication, planning and information design for teaching and learning within Vocational-Technical Education and Training Institutions in Malaysia, under the Ministry of Higher Education. However, a comparative method, mainly between the United Kingdom and Malaysia, in a number of case studies will be the approach adopted. This is because the research study will be primarily pursued in the United Kingdom under the supervision of the experts at Loughborough University, as well as other reasons as described in the following paragraphs.

1.1.2 Malaysia and the UK

The United Kingdom (UK) is by far the most important exemplar of educational integration and cooperation, and its development is often taken as a benchmark against which other countries or regions are measured (Beeson, 2007). While the Malaysian institutional educational system is not as coherent or established as that in the UK, especially as far as political cooperation is concerned, nevertheless there are substantial grounds for considering it as a discrete country in much the same way as we think of a newly developed branded product (Frank, 1998).
National identity issues may be an obstacle to institutional cohesion here because ‘all institutions are socially constructed and hence politically contested’ (Hurrell, 1995). There are, Hurrell (1995) suggests, two aspects of institutional cohesion: first, when an institution plays a defining role in relations between institutions and the rest of the world; and second, when the institution forms the basis for policy coordination within the institution itself. Nevertheless, *de jure* educational institutionalism, or formally organized cooperation, which is so characteristic of the UK, has proved more elusive. Malaysia, on the other hand, has thus far been associated primarily with *de facto* educational institutionalism, where cooperation amongst educational institutions is not as highly integrated or organised as in the UK.

For this assumption, although the main research is planned to be conducted in the UK for the reason of obtaining basic guidance or benchmarks, there might be the possibly comparative inputs from Malaysia which could be useful for development of appropriate guidelines and possibly will make a significant contribution of knowledge to the rapid growth in the integration of higher education.

The plan of conducting research in the UK and comparison with Malaysia also sought any cultural differences within learning and communication of using VCT; and from this relationship perhaps intriguing findings in relation to the shaping and reflection of cultural values and behaviour could emerge. The cultural issues were narrowed down to industrial design (ID) and engineering design (ED) education as different communities within a culture. This is essentially asking whether there is any difference in using the VCT for different audiences of student designers in the areas of ID or ED in their teaching and learning environments.
The Vocational-Technical Education and Training (VTET) system usually refers to the preparation of learners for careers that are based in manual or practical activities, traditionally non-academic and totally related to a specific trade, occupation or vocation. This educational sector is sometimes referred to as technical education, as the learners directly develop expertise in a particular group of techniques or technology (Wayne, 2007). However, the VTET practice in the Malaysian Polytechnics system (not other systems of the VTET that run in Malaysia under the supervision of different Ministries) is a system that has a combination of both academic-focused and technical-centred education, a 50:50 ratio system. The Malaysian Polytechnics accommodate students who are interested in pursuing their tertiary education with a technical and academic emphasis that allows them to achieve better employability.

Consequently, in some instances, these students who tend to pursue polytechnic programmes show slightly lesser academics results during their secondary education. This causes them to have less chance of securing a place in the Malaysian public universities than high achievers. As a twist, the polytechnics VTET become a stepping-stone platform for foundation programmes, thus allowing opportunities for these students to fulfil their university dream at later stage.

In addition, many years of annual tracer studies from the Department of Polytechnics, Ministry of Higher Education Malaysia show that the graduates from this VTET system have no problems in following the university programmes. As a matter of fact, these students may not be as strong academically as those students who are directly accepted by the university based on their secondary education; but, their performances in practical aspects are usually at least as competent, if not excelling. Hence, it is of compatible significance to study UK undergraduates (as benchmarking) of the 18 to 21 age range in order to compare with the Malaysian Polytechnics’ VTET groups of the same age range for this research purpose.
Moreover, the Centre of Instructional Development and Multimedia (CIDM) has been set up within the Department of Polytechnics since 2008 under the Ministry of Higher Education Malaysia to play the role of establishing the development of teaching and learning support for programmes run in polytechnics. This could play a crucial role in improving educational standards in Malaysia. Also, the curriculum development of a programme does not only comprise syllabus or content development, but also currently includes the teaching and learning strategies, assessment requirements and methodologies in order to provide sufficient information for teachers as guidance for complying with the minimum educational requirements in order to manage their delivery processes.

Thus, to ensure the success of this VTET implementation in the Malaysia polytechnics system, good information materials and the delivery systems (the communication aspects) are significant. The topic of this research, ‘the visual communication of technology’ in education must be taken into serious account in playing an important role in this context.

1.1.3 Design and Technology education

On a broader perspective, design and technology education and practice, especially in relation to visual cultures, is currently also one of the most important and timely areas of research amongst educators and practitioners in the field. This can be tracked from many published research papers and conferences originating from around the world since 2000 (i.e. Ashby and Johnson, 2003; Baynes, 2009; 2010; Codone, 2005; Danos, 2009; 2010; Engelhardt, 2006; George, 2007; Middleton, 2005; Musta’amal, 2010; Norman, 2000; 2006; 2008; Pedgley 2010; Spendlove, 2005; Simmons, 2008; 2010; Tringham, 2007; etc.).
Some of the conferences are: Design and Technology Association Education and International Research Conference, International Visual Literacy Association Conference, IDATER Online Conference, International Visual Methods Conference, Design and Practice Conference, Industrial and Intelligent Information International Conference, etc. These conferences are run annually in order to cater for worldwide needs for communicating and deliberating on the important and significant issues and findings.

Other disciplines such as researchers in cognitive psychology and computer science also frequently touch on the area of visual representations and cognition in learning, relating to their particular fields of interest (Barkowsky, 2010; Butcher and Kintsch, 2004; Carney and Levin, 2002; Hegarty, 2004; 2006; Mayer, 2001; Norman, 2004; Paley, 2008; Paoletti and Rigutti, 2008; Saund and Mahoney, 2004; Scheiter and Eitel, 2010; Shimojima, Katagiri and Enseki, 2010; Stieff, Hegarty and Dixon, 2010; and many more).

Visual modelling, designing, creativity and innovation are among those conceptual and physical components that have been most frequently linked together amongst this research in different disciplines, some as mentioned above. As to whether these intriguing links have empirical evidence, as yet there is little research evidence to support the assertions made. Cognitive psychologists found that it is very difficult to trace conceptual processes in the brain; however, design educationists were trying to prove the power of processing using visual methods for internal and external modelling with empirical evidence, e.g the works of Baynes (2009; 2010) and Pedgley (1999; 2010).
This area and its relation to visual communication is also currently actively and extensively being studied and researched by computer scientists in investigating diagrams within learning processes (this topic forms part of the literature review). In fact, the visual communication of technology has played a significant and important role since the Renaissance, particularly during the industrial revolution (Ferguson, 1993; Baynes and Puah 1978). However, since the engineering focus shifted from the arts and towards science during the 1900s, and also the birth of the computer beginning in the 80s, the faith in drawings or any other related visual methods has gradually faded in education, especially in engineering courses (Ferguson, 1993). Danos (2009) confirmed that today’s curricula, at any level around the world, do not seem to place any emphasis on visual literacy or graphicacy.

In today’s social and technological developments and requirements, many debates and arguments have been raised, and linked the developments in visual culture and multimedia to designing, creativity and innovation – especially, in the matter of how these are effectively being delivered through education. Thus, education has a major role to play in relation to this agenda, as it is charged with the responsibility of equipping the new generation with appropriate designing, creative and innovative skills.

These context and backgrounds to the research have set an appropriate position for the author to pursue her intention of undertaking the research in the matter of ‘visual communication of technology’ (VCT) and its efficiency in impacting on creativity and innovation within the perspective of industrial and engineering design education. The research and its outcomes are expected to be delivered to the Ministry of Higher Education Malaysia, in particular, developing teaching and learning materials for its polytechnic system; and it would seem that the visual aspect in communicating technological information could well have some contributions to make to the pedagogy of design education in general.
1.1.4 Research through designing

There have been ongoing debates over the legitimacy and efficacy of incorporating one’s own design practice, either in the form of a design project or several interconnected projects undertaken, within a PhD (Pedgley and Wormald, 2007). According to Pedgley and Wormald (2007), this debate has been hampered by a lack of practical examples of completed work or work-in-progress in the field of design. However, as in the records of the history of the UK universities, within mechanical and manufacturing engineering faculties, PhDs that reported the evidence base and rationale for designing or redesigning artefacts and systems have a long history. Thus, such debate over the legitimacy and efficacy of integrating design projects within a PhD can be seen to have arisen due to a lack of transfer of ideas and approaches within disciplines and faculties (Pedgley and Wormald, 2007).

The concept of design research, as referred to Archer (2004), can be outlined in one of these three modes: ‘research about design’, ‘research through design’, and ‘research for the purpose of design’. These proposed ideas of design research implied that the inclusion of personal design activity as an aspect of research had been given serious thought for over 50 years. Pedgley and Wormald (2007, p. 72) revealed that a reviving interest in ‘research through design’, or to be more appropriate, ‘research through designing’ can be traced to 1997, with a group of senior researchers (under the auspices of the UK Council for Graduate Education), published a study of ‘practice-based’ doctorates in art and design.

There were 3 examples of successfully awarded PhDs within the discipline of industrial design (Pedgley, 1999; Allen, 2002; Sener, 2004). The key aspects and differences of strategies employed for integrating design projects within a PhD are illustrated in Table 1.1.
These similar approaches were seen as appropriate and were considered to be part of this research methodology due to the need to generate data through case studies, and also because little empirical data has been found from literature review in supporting this research agenda.

<table>
<thead>
<tr>
<th>Three example PhDs incorporating design projects</th>
<th>Owain Pedgley</th>
<th>Jonathan Allen</th>
<th>Bahar Senor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year awarded</strong></td>
<td>1999</td>
<td>2002</td>
<td>2004</td>
</tr>
<tr>
<td><strong>Research aim</strong></td>
<td>To advance understanding of the information, knowledge, skills and values deployed by industrial designers when making decisions on product materials and manufacturing routes</td>
<td>To advance the design of, and champion new approaches to designing, products for people with severe communication disabilities and physical impairment</td>
<td>To investigate the phenomenon of modelling in industrial design, to evaluate the efficacy of current digital design tools for modelling, and to develop rationale for advanced next-generation digital modelling systems</td>
</tr>
<tr>
<td><strong>Key audiences</strong></td>
<td>Information providers Design educators Design researchers</td>
<td>Product designers Design educators Design researchers</td>
<td>Hardware/software developers Design educators Design researchers</td>
</tr>
<tr>
<td><strong>Purposes of design project(s)</strong></td>
<td>To generate case study data comprising documentary evidence of design activity, for subsequent analysis at macroscopic (strategic/resource) and microscopic (train of thought/rational) levels</td>
<td>To directly engage in investigating, understanding, and responding to the research area and research questions, thereby adopting designing as a mode of enquiry</td>
<td>To enable evaluation of state-of-the-art digital modelling technology (the Freiform® system) in commercial and academic contexts</td>
</tr>
<tr>
<td></td>
<td>To provide a vehicle for the development of data collection instruments and research methods suited to documenting design activity</td>
<td>To translate research data into coherent proposals for next-generation digital modelling systems, serving as a catalyst and pointer to future R&amp;D</td>
<td></td>
</tr>
<tr>
<td><strong>Contribution to design portfolio</strong></td>
<td>Fully working prototype polymer acoustic guitar</td>
<td>Fully working prototype communication device</td>
<td>Fast moving consumer goods concepts and rapid prototypes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Presentation quality concept illustrations of next-generation digital modelling systems</td>
</tr>
<tr>
<td><strong>Additional sources of primary data</strong></td>
<td>Interviews with practising industrial designers, design engineers and applied artists</td>
<td>Designing and modelling experiments with professional and student designers using three modelling media</td>
<td>Diary studies and interviews with industrial design undergraduates</td>
</tr>
</tbody>
</table>
1.1.5 **Research values**

This study anticipates contributing to our understanding of the following aspects:

- The associations within modelling, designing, creativity and innovation.

- Visual communication of technology in delivering technological knowledge, skills and values.

- Visual communication of technology within industrial and engineering design education.

1.1.6 **Personal motivations**

The author graduated with BSc (*cum laude*) in Graphic Design from Northeastern University, USA; and obtained Master of Technical Education from University Technology Malaysia.

After having almost five years of lecturing experience in the area of Graphic Design, the author was recruited to become a Curriculum Developer for the Malaysian Polytechnics (under the Ministry of Higher Education) and Community Colleges (currently under the Ministry of Human Resource). During the five years of this curriculum development career, the author was occasionally involved in courseware (teaching and learning materials) development, particularly in the areas of art, design and multimedia for those polytechnics and colleges.

The involved programmes included Art and Craft for Batik and Woodcraft; Graphic, Fashion and Industrial Design; Creative Multimedia for Animation and Video-Film Studies; and Print Media.

Since attaining design and technical education and qualifications, moreover having the opportunities as academic staff to be at the front line as well as behind the scenes of the educational planning and development team, the author was motivated to seek to establish principles behind the VCT.
These also allow the author to have a good chance to explore the links between the learning of technology through visual communication and associated creativity and innovation in industrial and engineering design education.

It is also significant to Malaysia where there is a desire to develop design education to support the emerging manufacturing and design industry in the current Malaysia Plan.

The author believes that with these backgrounds, it would be appropriate for her to research within this field.

1.1.7 **Problem statement of the study**

The discussion of the visual communication of technology would be seen as a global phenomenon instead of just an issue for the UK or Malaysia.

Visual communication of technology (VCT) has been significantly and intensively used since the Renaissance and particularly during the industrial revolution (Ferguson 1993; Baynes & Pugh 1978; Baynes 2009). It has been a key communication and concept development tool for designers or inventors, engineers, clients, manufacturers and others during that period of time. Also, visual communication (VC) practices have been previously and extensively researched in relation to the history of technology (Ferguson 1993). Nonetheless, visual literacy or graphicacy, the fundamental element of learning visual communication, does not seem to have been given any emphasis in current curricula at any level around the world (Danos 2009).

The issues of VC are increasingly becoming important topics for discussion and debates among design and technology educators, designers and related organisations worldwide. Associated issues have emerged concerning the effective delivery of education to equip the next generation with appropriate designing, creative and innovative skills.
It is often asserted that VC can support the development of such skills, which discusses further in literature review (section 2.2, page 33-36). However, there is little research evidence to support this assertion. Genuine designing is a creative activity (Thistlewood 1990), but the evidence available so far does not track direct links from VC through perception and learning to modelling and designing, and then to facilitate creative and innovative design outcomes.

1.2 Research Purpose and Focus

The purposes of this research concern:

- Visual communication of technology (VCT)
- Claims of VCT supporting designing and stimulating creativity and innovation
- Criteria that help the development of VCT
- Technologies in industrial design (ID) and engineering design (ED)
- Cultural concerns: Malaysia and the UK; ID and ED (different communities in a culture)
- Improvement of visual tools for ID and ED education for the Polytechnics, Ministry of Higher Education Malaysia (relates to Case Study-3)

These purposes are to be explored through the following aims and objectives.

1.2.1 Research aims

This research aims aiming to explore visual communication methods used in today's technology and its communication aspect in the pedagogy of ID and ED education.
The primary foci of the study are about:

- Gathering empirical evidence concerning the association of the VCT, designing, and creativity and innovation.
- Establishing the key principles of VCT
- Identifying and defining the effectiveness of visual-technological-information (VTI) design, and its impact on ID and ED students within the 18- to 25-year-old age range (diploma and undergraduate) within several institutions around the world.

The research initiates from:

- Surveying key graphical principles and techniques behind the development and design of visual communication tools in order to establish key emerging principles (KEPs) of VCT.
- Analysing existing visual tools from the past and current practice in order to have deeper understanding and further articulate the KEPs of VCT within the VTI design.
- Applying the KEPs for a series of tests (design and redesign) of VTI in order to examine their reliability and validity.

The analyses involved include:

- A designing exercise and its evaluation of creative-innovative within a context.
- A series of visual information comparisons and analyses via an eye-tracking experiment.
- A series of designs and redesigns applying KEPs and analysis of the existing VTI from books and scholarly papers.
Findings of the study are sought from different directions: the researcher’s/designer’s own analyses (based on evidence gathered and established principles from literature), the users’/participants’ and the experts’/authors’ feedbacks in order to obtain validity of the research data. The goal of this research is to understand the principles behind the development of visual communication of technology, and to establish guidelines for future educational/instructional design development teams for the teaching-learning materials.

1.2.2 Research objectives and the corresponding questions

The following research objectives and questions are used to guide the research study:

**Research questions related to Objective 1:** To investigate the principles behind the communication of technology, predominantly focusing on the general visual communication of technological information.

1. What is visual communication?

2. How is visual communication used to communicate knowledge of technology?

**Research questions related to Objective 2:** To explore the learning of technology through visual communication and achieving creativity and innovation in designing.

3. What are the links between visual communication of technology, designing, creativity and innovation?

**Research questions related to Objective 3:** To explore and evaluate existing visual communication tools or resources for industrial and engineering design teaching and learning environments.

4. What is industrial design (ID)?

5. What is engineering design (ED)?

6. What are the technological information requirements for ID and ED?
7. What are the effective methods for visual communication of technological information?

8. How is visual communication used to communicate technological information to ID and ED student designers (within the 18 to 25 age range) at higher education around the world?

1.3 Research Outline

The outline of this research programme is explained in the following manners:

- Literature review
- Research structure and framework
- Data collection strategy

1.3.1 Literature review

The literature review that was undertaken enabled the questions related to the research to be formed, and to some of those questions, answers could be found from this secondary research data. The context of the research in terms of technology and technological information for Industrial Design (ID) and Engineering design (ED) within the visual communication of materials technology, therefore, were able to be explored and built upon a developing theoretical framework for the research.

Various resources such as books, journals, conference papers, periodicals, and online resources were reviewed. Online resources that were searched included: MetaLib, Loughborough University Institutional Repository, Loughborough University Online Public Access Catalogue (OPAC), and Google Scholar.

Initially, many sources were found. An initial Google Scholar search identified 1,700,000, which were too many sources for one researcher to read.
Consequently, the search was narrowed down using more defined keywords until about 200 potential references remained. The academic search engines via MetaLib and a targeted categories search also helped in reducing the number of references. Table 1.2 summarises examples of these searches.

<table>
<thead>
<tr>
<th>No.</th>
<th>Keywords/Recommended Articles</th>
<th>Google Scholar</th>
<th>Zetoc</th>
<th>ASSIA</th>
<th>DATER</th>
<th>ISI Web</th>
<th>Soc. Abs.</th>
<th>BHI</th>
<th>Article 1st</th>
<th>Relevant/Selected Reading *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visual communication of technology</td>
<td>1,700,000</td>
<td>239</td>
<td>16</td>
<td>30</td>
<td>559</td>
<td>605</td>
<td>22</td>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Visual communication of technology in learning technical information</td>
<td>177,000</td>
<td>19</td>
<td>0</td>
<td>30</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>Visual communication literacy</td>
<td>97,800</td>
<td>88</td>
<td>5</td>
<td>2</td>
<td>92</td>
<td>139</td>
<td>4</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Visual communication graphicacy</td>
<td>289</td>
<td>13</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Technical visual communication</td>
<td>475,000</td>
<td>160</td>
<td>2</td>
<td>69</td>
<td>168</td>
<td>115</td>
<td>2</td>
<td>75</td>
<td>62</td>
</tr>
<tr>
<td>6</td>
<td>Visual communication design</td>
<td>262</td>
<td>31</td>
<td>3</td>
<td>1032</td>
<td>323</td>
<td>32</td>
<td>146</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Technical information design</td>
<td>46</td>
<td>67</td>
<td>40</td>
<td>3875</td>
<td>635</td>
<td>7</td>
<td>360</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Eye tracking method</td>
<td>19</td>
<td>5</td>
<td>0</td>
<td>108</td>
<td>15</td>
<td>0</td>
<td>5</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Eye tracking research in design</td>
<td>14</td>
<td>3</td>
<td>0</td>
<td>72</td>
<td>13</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Recommended sources by supervisors and related experts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

*Initially selected relevant readings. More has been recommended and selected since.

Table 1.2
Example of the literature searching events
Besides these searching methods, references from the found sources were also very helpful. Quite a number of relevant sources were successfully traced, e.g. from a relevant journal article, a whole series of the ‘Diagrammatic Inferences’ conference proceedings were found, and more relevant articles were gathered and used in this thesis’ literature. However, very few sources provided evidence of links between visual communication, technology, designing and innovation.

1.3.2 Research structure and framework

Figure 1.1 outlines an ideal representation of the research structure. It features an hourglass model as broad aspects at the top (or beginning) and bottom (or the ending section); and it gets more focused towards the middle-narrowed-section of the diagram. In other words, this middle section will be the ultimate emphasis for the main research areas in this research programme.
The research programme is accomplished through an approach based on multiple levels of triangulations. The overall research agenda begins with a macro triangulation framework for the empirical research. It is with a total number of three case studies to be plotted under this macro triangulation (Figure 1.2). Subsequently, each aspect of the triangulation features further another cycle of its own micro triangulation for the purpose of gathering reliable sources of data (Figure 1.3; detailed methodology to be shown and explained in Chapter 3). Consequently, a verifying round of the evidence over each micro triangulation is planned to validate the overall measurement of the conduct (Figure 1.3).

![Figure 1.2]
Macro Triangulation of the Research Project
1.3.3 **Data collection strategy**

Table 1.3 summaries the overall research strategies for gathering the empirical data in relation to the research objectives and questions. The data collections are mainly accomplished by at least three sources or methods of enquiry – the means of ‘triangulation’, which includes various conduct and strategies for each micro triangulation (also identified in Table 1.3). This is to ensure both qualitative descriptions and quantitative measurements are attained; and it is all about achieving corroborative empirical evidence, and hence reliable and valid research.

For some questions, the gathering of data was ended by the literature review because the information is already acknowledgeable as reliable sources by many credible experts; therefore, further verification of evidence is considered unnecessary.
**Objective-1:** To investigate the principles behind the communication of technology, predominantly the general visual communication of technological information.

1. What is visual communication? **
2. How is visual communication used to communicate knowledge of technology? **

**Objective-2:** To explore the learning of technology through visual communication and achieving creativity and innovation in designing.

3. What are the links between visual communication of technology, designing, creativity and innovation? **

**Objective-3:** To explore and evaluate existing visual communication tools or resources for industrial and engineering design teaching and learning environments.

4. What is industrial design (ID)? **
5. What is engineering design (ED)? **
6. What are the technological information requirements for ID and ED? **
7. What are the effective methods for visual communication of technological information? **
8. How is visual communication used to communicate technological information to ID and ED student designers in higher education around the world? **

**Research Strategies**

<table>
<thead>
<tr>
<th>Literature Review</th>
<th>Case Study-1 (CS1)</th>
<th>CS2</th>
<th>CS3</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main source</strong></td>
<td><strong>Subsidiary source</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.3**
Research Strategy for identifying data collection methodologies
1.4 Thesis Overview

The thesis is structured with nine chapters as illustrated in Figure 1.4, and it also consists of references, appendices and annexes.

1.4.1 Chapter One [Introduction]

Chapter One provides the background of this research and reveals the author’s personal motivation for undertaking this PhD research study. It defines the purpose of this research and its foci by stating the research problems, aims, objectives and questions to be explored. The value of the research agenda is anticipated, and the overall research plan and data collection strategies are outlined. The chapter also includes an overview of the thesis structure to guide the reader through this work.

1.4.2 Chapter Two [Literature Review]

Chapter Two provides reviews of literature in the areas of visual communication and technical information design; technology for industrial and engineering design; the association of modelling, designing, creativity and innovation; and principles and techniques of graphical practice, instructional and information design. This analysis leads to emergent principles of VCT for subsequent empirical investigation. Prior research concerning diagrammatic representations and the use of eye-tracking as a research tool is outlined.

1.4.3 Chapter Three [Research Plan]

Chapter Three provides an overall plan of this research and describes the approaches, design frame and methodologies undertaken throughout the research data gathering. It explains the role of triangulation, corroborative evidence, and a mixed research methods strategy, and how these provided evidence to explore the research questions. It also discusses the research sampling and selection, and related issues in achieving reliability and validity of the research findings.
Chapter 1 Introduction

Structure of This Thesis:

Chapter 1: Introduction
- D&T Education; Modelling, Designing, Creativity & Innovation
- Context: Technology for ID & ED; Material
- VC & Tech-info. design; Principles & techniques for 2D visuals
- KEPs of VCT
- Diagrammatic; Eye-tracking research
- Summary: Key issues

Chapter 2: Literature Review
- Context & Theoretical Framework
- Applied to Cases

Chapter 3: Research Plan
- Principle & Approach: Strategy; Reliability-Validity; Triangulation; Mixed Methods
- Research Design
- Methodology: Methods correspond to RQs; Eye-tracking; Data Collection
- Sampling & Selection Instruments

Chapter 4: Redesigning...
- Redesigning images using KEPs of VCT: Kite-technology
- Material-technology

Chapter 5: Case Study 1:
- VCT > Designing > Creativity/Innovation

Chapter 6: Case Study 2:
- KEPs of VCT

Chapter 7: Case Study 3:
- VCT in Context

Chapter 8: Discussion
- Review, Reflection and Relevance to:
  - Case Study 1
  - Case Study 2
  - Case Study 3
- Answering the Research Objectives

Chapter 9: Conclusion
- Relevance to RQs
- Contribution to knowledge
- Recommendation for further research & development

Figure 1.4 Structure of This Thesis
1.4.4 **Chapter Four [Redesigning Images Using Key Emerging Principles of VCT]**

Chapter Four reveals the analyses of existing resources, and illustrates the design and redesign processes based upon the criteria of the key emerging principles (KEPs) of VCT within the visual-technological-information of kite and materials technologies.

1.4.5 **Chapter Five [CASE STUDY-1: VCT > Designing > Creativity]**

Chapter Five describes how the first case study was conducted, and results were obtained and interpreted. Detailed case study design, selection of visuals, and data collection methodologies are described, and associated reliability and validity concerns are discussed.

1.4.6 **Chapter Six [CASE STUDY-2: KEPs of the VCT]**

Chapter Six illustrates how the second case study was conducted, and how the results were obtained and the data interpreted. Detailed case study design, selection of visuals, and data collection methodologies are described. Issues concerning the reliability and validity are discussed.

1.4.7 **Chapter Seven [CASE STUDY-3: VCT and KEPs In Context]**

Chapter Seven demonstrates how the third case study explored VCT in context. It describes how the case study was carried out and results obtained. Case study design, selection of visuals, and data collection methodologies are described; the collected data is interpreted and reported. This chapter also discusses the associated reliability and validity.

1.4.8 **Chapter Eight [Discussion]**

Chapter Eight discusses the outcomes from the three case studies in relation to the literature reviews and the contribution of the research in relation to the research objectives.
1.4.9  **Chapter Nine [Conclusion]**

Chapter Nine concludes the findings of the research and reflects on the contribution of knowledge. Recommendation for possible further research and development are discussed.

1.4.10 **References, Appendices and Annexes**

A list of references, Appendices and Annexes are placed at the end of this thesis. The annexes contain with audio recordings, video clips of eye movements and scanning paths from the participants in the research case studies.
Chapter 2 Literature Review

Chapter Overview

Chapter Two provides reviews of literature in the areas of visual communication and technical information design; technology for industrial and engineering design; the association of modelling, designing, creativity and innovation; and principles and techniques of graphical practice, instructional and information design. This analysis leads to emergent principles of VCT for subsequent empirical investigation. Prior research concerning diagrammatic representations and the use of eye-tracking as a research tool is outlined. Figure 2.1 shows how Chapter Two fits into the structure of this thesis.

Figure 2.1 Chapter 2 in the Structure of Thesis
Figure 2.2 illustrates the storyboard of the literature reviews and also depicts the focusing of the research area.

Figure 2.2
A Storyline for Literature Review
2.1 Design and Technology in Education

The general meaning of ‘technology’ (Pacey, 1983) can be viewed in terms of the technology practice, which has three main aspects, namely cultural, organisational and technical, as shown in Figure 2.3. The elaboration of these three aspects (Pacey 1983, p. 6) was:

- **Cultural** – refers to goals, values and ethical codes, belief in progress, awareness and creativity.

- **Organisational** – relates to economic and industrial activity, professional activity, users and consumers, trade unions.

- **Technical** – concerns the knowledge, skills and technique; tools, machines, chemicals, livewires; resources, products and wastes.

The technical aspect in Pacey’s (1983) ‘technology model’ (which he described as a restricted meaning of technology) is where designing is perhaps most commonly related to technology. However cultural issues, such as values, and organisational aspects such as economic organisation, also have influence on designing.

![Diagrammatic Definition of 'Technology' and 'Technology Practice' cited in Pacey, 1983, p. 6](image)
Norman (2008, p. 17) revealed that within designing processes, the technological boundary for designers is their knowledge, skills and values. He provided a theoretical position of technology for design (which was depicted as the 3 strands of a cord, representing knowledge, skills and values) and which surrounded a model of designing (2000, p. 129), as shown in Figure 2.4. This model of designing was proposed and discussed by Roberts (1992); and the origins of Norman’s proposal could be found in the work of the APU\(^1\) (Hicks, et al., 1982), and earlier traced to the Design in General Education Project completed at the Royal College of Art (Archer, et al., 1979).

Norman also concluded that at a micro-level, technology is seen as “a containing influence on designing; instead at macro-level, it is as the means through which society creates its material culture in the manner of Arnold Pacey” (Norman 2008, p. 17).

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\(^1\) Assessment of Performance Unit (APU) produced a document entitled, ‘Understanding Design and Technology’, a framework for Design and Technology education at primary and secondary level within the United Kingdom. The document was submitted in the Summer of 1980.
According to Hicks, et al. (1982, p. 5), design activity seeks to resolve specific practical problems through the integration of a wide range of knowledge and experience. To further understand the essence of design and technology, ‘knowledge’ was discussed using the following technological concepts:

- **Control** concerns the factors influencing the man-made environment, it is necessary to know how systems, static or dynamic, can be created for a specific purpose;

- **Energy** involves knowledge of sources, cost and forms of energy; of methods for storing and transmitting energy; and of efficiency and the conversion of energy; and

- **Materials** selection requires knowledge of their sources and cost; and whether they need to be further processed, manipulated and connected.

‘Skills’ which are used in design and technological activity, based on Hicks, et al. (1982, p. 4), were categorised as:

- **Investigation** incorporates an ability to identify design problems, and via designerly activity, produce a resolution, system or product through experimentation;

- **Invention** includes “the ability to initiate and develop ideas” (Hicks 1982, p. 4), and by illustrating those ideas through drawing and making, creating alternative resolutions;

- **Implementation** of the design decisions is taken across a range of designerly activity, and the most appropriate resolution is selected; and

- **Evaluation** demonstrates an ability to create a system or design a method for testing, coupled with an ability to see which of the proposed resolutions to the design task are judged the most successful.
The framework that was proposed to assess ‘values’ in the APU’s document, included:

- **Technical** values which involve the practitioners’ application and understanding of the approach designers or design students take to concepts like efficiency, flexibility, precision and confidence;

- **Economic** values were described as being about the understanding the differences between value, price and cost. It considers the value of the product or system in use, its intrinsic value and its worth in terms of exchange;

- **Aesthetic** values concern the individual perception of forms and colours that help to communicate an idea, a meaning, or an expression; and

- **Moral** judgements are concerned with legislation and learning, for example an awareness of the “natural environment and his responsibility for its and his own future survival” (Hicks et al. 1982, p. 7).

An example of design and technology activities: a project on ‘Aerial Photography’ at St Birinus School, Didcot, Berks with 13 year old children, was presented by Hicks (1982, p. Appendix II), to illustrate the technological aspects and competencies undertaken. Table 2.1 only demonstrated 1 out of 4 parts of the activities, which was on ‘Structural Design’. The technological concepts involved include: **Control** and **Materials** (under ‘Knowledge’ aspect); together with **Invention** and **Investigation** (under ‘Skills’ aspect). In terms of ‘Values’, Hicks (1982) did not provide further examples in the APU document.
### KNOWLEDGE - the three strands of technological concepts

<table>
<thead>
<tr>
<th>CONTROL</th>
<th>ENERGY</th>
<th>MATERIALS</th>
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<tr>
<td><strong>B. Structural Design</strong></td>
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<tr>
<td><strong>INVESTIGATION</strong></td>
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<td></td>
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<tr>
<td>1. Find out what maximum weight a given kite can carry (payload)? Find out the effect of loading with camera on the control and lift of the kite?</td>
<td></td>
<td>3. Find out the strength, and the nature of the strength, needed for connections and members (tensile, compressive, impact, elasticity, etc.)?</td>
</tr>
<tr>
<td>2. Find out the importance of attitudes (orientation) of the kite to wind?</td>
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<td>4. Find out how force induced by air flow over the surface is transferred member by member to the string and to the camera?</td>
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<tr>
<td><strong>INVENTION</strong></td>
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<tr>
<td>5. Think of ways of attaching the camera to the kite, or to the string? Use knowledge of strengths needed to generate detailed ideas for members and joints?</td>
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<td></td>
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<tr>
<td>6. Make a rational choice of materials for construction of frames? Make a rational choice of structural systems, joints, etc?</td>
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</table>

| Table 2.1 Design and Technology Activities: Structural Design for Aerial Photography |
Knowledge, skills and values in technology for design can each be the topic of research as these aspects are wide-ranging and ever-evolving, e.g. each of these areas of technology for design can be further developed into a new agenda for research by itself. A number of existing examples are as listed below.

Related research to knowledge in technology for design:

- Pedgley’s PhD Thesis (1999): *Industrial designers’ attention to materials and manufacturing processes: analyses at macroscopic and microscopic levels*


Related research to Skills in technology for design:

- Simmons’s PhD Thesis (2010): *Exploring website effectiveness and the influence of the Sustainable Design Award website on decision-making concerning sustainability within AS/A2 design and technology*


Related research to Values in technology for design:


For this research this concept of technology for design as the summation of knowledge, skills and values has provided a key aspect of the theoretical foundations. A further insight toward the associations within modelling, designing, creativity and innovation are now explored. In particular the investigation will focus on how this technological knowledge, skills and values can be delivered through visual communication (VC) to enhance the teaching and learning processes.
2.2 Modelling, Designing, Creativity and Innovation

Published research exploring cognitive modelling and teaching and learning, includes the following contributions.

Middleton (2005) suggested that design and technology learning at school level is complex and requires higher-order thinking through visual mental imagery and manipulation of concrete materials in situations and contexts that are made meaningful to students for designing.

Storer, Badni, Bhamra and Farmer (2005) provided evidence of posters effectively communicating complex issues associated with sustainable design amongst post-16 students (project initiated by Practical Action, formally ITDG). However, Simmons (2008) revealed a vast majority of students were not using the sustainability online resources to support their sustainable design decision, although they knew the resources were available for them to use.

The cognitive theory of multimedia learning by Mayer (2009) suggested that learners first build two separate mental models of information sources (text and diagrams) in isolation, and then integrate them into a single coherent mental representation with the help of prior knowledge.

However, in Scheiter and Eitel’s study (2010) results obtained indicated that signals highlighting the relation between text elements and corresponding diagrammatic elements improve the ability to understand, and hence required the integration of both representational formats as functional interrelated components (not isolated elements). ‘Signals’, as referred to by Scheiter and Eitel (2010, p. 265), is about highlighting relevant information in the text (e.g. underlining, italics, bold-face, enumeration etc.); or in the diagram (e.g. by inserting arrows or using colour and contrast etc.).
In addition, published research exploring modelling, including cognitive modelling, designing, and its support through using visual communication to creativity and innovation within the educational environment and real world practice, includes the following contributions.

Baynes (2009) presented many examples of cognitive modelling and the links to designing and innovation. Examples he provided cover many professions, some examples of them include:

- Cool acoustics polymer guitar designed by Pedgley and Norman (1999): involved modelling and designing processes which employed many visuals that support creativity, e.g. talking-sketches, thinking-sketches; constructive-sketches; checklists; assembled and exploded drawings; final visuals and used of innovative materials (examples of visuals used as shown in Appendix 2.1) (Baynes 2009, p. 33-40).

- Musical and fireworks event by World Famous: modelling and designing activities involved: live music, flame, smoke, changing lights, a blazing symbolic tree and extraordinary pyrotechnics; visuals for the innovative event include: design sketches, technical drawings, 3D CGI, lighting plans, and firework designs (as shown in Appendix 2.2) (Baynes 2009, p. 63-66).

- City Palace Tower of Moscow (2005-2010): visuals used to develop ideas (the modelling and designing processes), as the communication language and to achieve innovation, include: shorthand sketch, development drawing, CGI image, 3D model, linear and digital drawings, simulation and presentation drawings (as shown in Appendix 2.3) (Baynes 2009, p. 73-81).

Similarly, Carlson and Gorman (1992) found that tacit knowledge via viewing and manipulating objects stimulates new ideas that help in the process of invention. Curtiss (1987) and Codone (2005) reported that imagery helps achieving higher levels of thinking within creativity and problem-solving. These were parallel to Ferguson’s (1993) findings of visual tools were the main elements used in communicating thoughts and stimulating meaningful relationships in order to develop new ideas in problems-solving and inventions.

Whilst, Norman (1998, p.81) indicated, “It is possible to speculate that technological representation in visual form facilitates cognitive modelling and its synthesis with aspects of form.” Baynes (2009, p. 37) also shared a similar perspective of this cognitive modelling, by emphasising “The ‘dialogue’ in the mind between internal and external models provides a working space for creativity.”

The above statements were supported using empirical evidence by Pedgley (2010), who revealed that ‘sketching’ progresses as a dialogue between the designer’s mind and the modelling medium [note: internal and external visual formations evolved].

According to Pedgley (2010, p.23), they had the purposes of: explanations to colleagues [note: use visual to communicate], mementos of ideas coming from existing products, restating design ideas and archiving information, recording ideas and decision taken at meetings [note: use visual to stimulate ideations], and generating and developing product designs [creativity/innovation emerged].
The ‘[note:]’ indicators have been added by the author in order to highlight the links of visuals to communication, to modelling and stimulations, and finally ended with creative or innovative outcome.

In fact, visual thinking or modelling and its link to creativity and innovation have a strong historical support. Ferguson (1993, pp. 41-42) stated that the primary engineering information was recorded and transmitted in visual language, and has proven to help the thinker (designer/engineer) to expand their thinking and sensory experience – which is to convert the image in the mind's eye to usable visual information. The significant visualization tools since the Renaissance were pictorial perspective, orthographic projection and graphic symbols used in engineering drawings (Ferguson, 1993).

Great historical figures who used these approaches – visual thinking as analysis, and for the synthesis process or creating the ‘unknown’ from the ‘known’ (Ashby and Johnson, 2004) – include Leonardo da Vinci; Newton; Einstein and many other famous inventors recorded in our history. For instance, Leonardo da Vinci, a well-known example, extensively used complex sketches, annotations and other types of visuals in analysing his studies and observations from the surrounding nature. His works from the 16th Century has continued to assist developments and inventions of many technologies and sciences. Hence, the following would be a commonly held view:

“The power of the visual image lies in the ease with which it can be manipulated by the mind and its ability to trigger creative thought.”

(Ashby and Johnson 2004, p. 31)
Creativity, on the other hand, has been defined in many ways by various researchers based on their areas of interests and their different perspectives, rather than having a universal definition (Dewulf and Baillie 1999, p. 5). It has been considered to have an ‘elusive definition’ with a wide variety of possibilities by NACCCE\(^2\) (Blair, 1999). It is also a concept which is categorised as ‘ambiguous and problematic’ to be understood (Dakers 2004, p. 29).

Likewise, Spendlove (2005, p. 9) characterised ‘creativity’ as a complex topic in nature and it remains a ‘slippery concept’, which is difficult to be determined, nebulous and awkward to be defined.

Some examples or associations of creativity are:

- It is always linked to ‘creative thinking’ or ‘ability’, ‘problem solving’, ‘imagination’ or ‘innovation’ (El Murad and West 2004, p. 189); and the creative ideas, according to them, “must be new, unique, and relevant to the product and to the target audience in order to be useful as solutions” (2004, p. 188).
- It is “something associated with new product” (Altiers 1988, p. 155).
- It is the ability to generate products (e.g. ideas, methods and forms) that are meaningful and uncommon to others (e.g. Sternberg and Lubart, 1999; Amabile, 1996; Gardner, 1989; Barron, 1969; Jackson and Messick, 1965).
- A creative idea is both ‘novel and useful’ (Martindale 1995, p. 250); however, he suggested, the novelty does not necessary exist from something totally new, instead it could emerge from the ‘new combinations of the old ideas’ (ibid, p. 250).
- It is ‘the disposition to make and to recognize valuable innovations’ by Laswells (cited in Gilchrist, 1972, p.10).

\(^2\) National Advisory Committee on Creative and Cultural Education.
The list of creativity or creative ideas can be just carried on in various manners and without limits. As Spendlove (2005, p. 9) emphasised, “the differing perspectives on creativity are ultimately driven, changed and manipulated depending upon the prevailing educational, political and economic imperatives of the time.” However, the intention of this research is not to define creativity, but it forms an aspect of the research context for the exploration of the visual communication of technology. This research was intended to seek its links within the design processes, particularly in an educational environment for ID and ED education, and whether the VCT has any impact or influence in achieving it.

Thus, creativity in an educational context is the main concern and more relevant to this research study. According to Spendlove (2005, p. 9), creativity in education can be considered in one of these two states:

1. Creativity – “can be defined as a feature of elitist high-level intelligence – innate and prominent in the gifted few and not considered as something that can be taught;” or

2. Creativity – “can be recognised in all students to be facilitated and nurtured as an essential life skill, delivered across the school curriculum at all stages to restructure their own world and develop what Bandura (1995) refers to as ‘self-efficacy’.”

In addition, Spendlove (2005, p. 9) added that ‘ethicacy’, ‘originality’ and of ‘some value’ are those key features of creativity within education, which must be compromised in both stages.

Thus, this research set out to establish the key principles of VCT (Beh and Norman, 2009), aiming to empower designers through communicating technological information; and the articulation of key principles to achieve this in various contexts.
Specifically, the research targeted the efficiency of VCT in supporting designing in industrial and engineering design (which is discussed in the following section, 2.3), and associated creativity and innovation.

Visual communication (VC), on the other hand, can be the means for imparting awareness relating to key messages and guidance in important emerging design areas, such as sustainable development. Many sustainable design guides, tools and websites are readily available online; however, recent research shows there is limited use of these existing resources (Simmons, 2008). This situation could be addressed through VC. Visual communication and the design of technical information will be explored in section 2.4.

2.3 The Context of this Research

The research programme was established to explore the impact of VCT within industrial design (ID) and engineering design (ED) education, particularly the visual information used in teaching and learning processes. Hence, some differences between the ID and ED environments and requirements are noted before focusing on the detailed context of this research. It is also noted that, this research was not about the differences between ID and ED; rather, it was about the concern of VCT within their practices in supporting creativity and innovation.

2.3.1 ID versus ED

Within product design, ‘designing’ of different goods requires different combinations of ID and ED skills. Typical ID skills, as described by Pei (2009, p. 57), are concerned with the user-related aspects of product appearance; where form, usability and personality of product are to be focused by employing the use of visual design representations to externalise and communicate its ideas (also supported by Kim et al., 2006; Oakley, 1990; Wikström, 2001).
However, typical ED skills relate to the structure, function and manufacture of the product, which involve problem definition, conceptualisation, embodiment and detail design (Shigley and Mischke, 1989; Pahl and Beitz, 1996; Ullman, 2003).

Both ID and ED use representations to better understand the problem and to communicate with others (Pei 2009, p. 61; cited from Burghardt, 1999). However, the visual representation for ED would only display a detailed description of a design proposal for manufacture, not an artefact form (Dym and Little, 2003), and tend to be more calculations-based, presenting technical data and are usually very precise (Pei 2009, p. 61). Examples of the differed ID and ED visual presentation skills, identified by Pei (2009) are shown in Figures 2.5 (for ID) and 2.6 (for ED).

This is similar to Ferguson’s exploration of the direct design of the artisan as compared to engineering design drawing; although there are differences in format, the conceptions of the two remain the same (1993, p. 5).

In both cases, the design begins with an idea, as expressed by Ferguson (1993, p. 5), they are “sometimes distinct, sometimes tentative, which can be thrown on the mind’s screen and observed and manipulated by the mind’s eye.”
In accordance with Cagan and Vogel (2002), differences between ID and ED are mainly due to perceptual gaps or differences in perspective. Industrial designers are visual thinkers concerned with aesthetics; whilst, engineering designers think in terms of function and cost.

Likewise, Wu (2012) concluded that ED students are conceptually based and have one-direction thinking for problem-solving; in contrast, ID students’ thinking in their minds is very complex, and they always search for multidimensional solutions for problems, which makes them more connected to the complexity of the real world.

Ashby and Johnson (2004, p. 29) expressed ‘designing’ for ED as a linear and sequential thinking model, using verbal reasoning and mathematical procedures to establish an absolute and precise specification – it moves from the ‘known’ to ‘unknown’ by analysis. This description is closely parallel to the common representation of engineering design activities presented by Pugh (1990, p. 11) as shown in Figure 2.7.
All models of designing have a “relationship to its true nature, where the fundamental nature of the problem changes from ill-defined to defined,” (Figure 2.8) during the designing process, as portrayed by (Cross 1983, p. 11). Different models of designing reveal different aspects of the activities, and these linear models of designing might be considered more useful in describing the resolution of design problems as they become better defined. ‘Designing’ for ID is described as “dissecting, recombining, permuting and morphing ideas and images” (Ashby and Johnson 2004, p. 30).

Additionally, they implied that designing in this area utilises images both to remember and to imagine. Baynes (2010) analysed and explored the visual acuity and modelling capability to develop proposals for future designs. He elaborated as follows:

“The mind’s eye of *homo sapiens* has evolved in such a way that we can remember and model the past, consciously experience the present and speculate and model possible futures.” (Baynes 2010, p. 18)

The aspects that engineering design (in general) supports are: the product’s “physical principles, mechanical system, and proper technical functioning such as its mechanical and thermal performance, cost and durability” (Ashby 2005, p. 12; Ashby and Johnson 2004, p. 27). It is about how a product works and how it is made.
The priority in industrial design is: to sustain the personality and “satisfaction afforded by the product, referring to the visual and tactile attributes, associations and perceptions, and historical antecedents” (Ashby and Johnson 2004, p. 27). It can be seen as an aesthetic and perceived values that the product character is described by the demand of clients.

2.3.2 Technology for ID and ED

Ashby and Johnson (2004, p. 27) revealed that a successful product is created based on sensible and synthesised process analysis aspects of engineering (most commonly recognised as ‘technical’), and industrial design. The balance of inputs depends on the nature of requirement for the individual product and the emphasis of skills. An approximate relationship between ID and ED has been simplified (Carter 1977, p. 13) as shown in the design spectrum (Figure 2.9), where “different classes of product have different associated knowledge bases and varying emphases in the modelling methods that are used” (Norman 2002, p. 29).

![Figure 2.9](image)
For instance, cutlery design requires more of the ID skills as compared to ED, whereas machine tool design demands intensive ED skills rather than ID. The different design programmes offered around the world are inclined to address particular classes of product to allow the students to attain adequate understanding of the related modelling methods. According to Norman (2002, p. 29), this is also employed to reach a satisfactory resolution of the design issues. Within these classes of product in the design programmes, the position of technology for design remains bound to the knowledge, skills and values available to those carrying out the designing activities.

Based on Myerson’s report in 1991 (a survey of higher education, employers and relevant literature concerning technological change and industrial design education), a range of technological content was identified for product and industrial design degree courses in the UK. They are: materials, processes, human factors, computing, workshop practice, manufacturing, information management, engineering science, mechanical engineering, and electrical/electronic engineering (Table 2.2) (Norman and Wormald 1996, p. 1; Myerson, 1991). To be more exact, those course contents that made up to ID programmes are from item no. 1 until item no. 7; whereas for ED the course contents are up to item no.10 in Table 2.2.
Range of technological content found on product and industrial design courses in the UK

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<th>1. MATERIALS</th>
<th>6. MANUFACTURING</th>
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<td>Properties</td>
<td>for Manufacturing</td>
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<td>Structure</td>
<td>Techniques Used in Design</td>
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<tr>
<td>Strength, Testing and Failure</td>
<td>for Manufacturing</td>
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<td>Selection</td>
<td>Planning</td>
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<th>2. PROCESSES</th>
<th>7. INFORMATION MANAGEMENT</th>
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<td>Product Data: Location and Usage</td>
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<td>Constraints</td>
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<td>Polymer Processing</td>
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<td>Methods, Applications and Design</td>
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<td>Constraints</td>
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<td>Other Processes</td>
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<td>Finishing Processes</td>
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<tr>
<td>Joining, Fastening and Fabrication</td>
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<th>8. ENGINEERING SCIENCE</th>
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<td>Anthropometry</td>
<td>Stress and Strain</td>
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<tr>
<td>Anatomy, Physiology and Psychology</td>
<td>Energy and Power</td>
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<tr>
<td>Ergonomics</td>
<td>Control</td>
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<td>Man/Machine Systems</td>
<td>Thermodynamics and Fluid Dynamics</td>
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<td>Statics and Dynamics</td>
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<th>4. COMPUTING</th>
<th>9. MECHANICAL ENGINEERING</th>
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<td>2D Draughting</td>
<td>Friction, Fatigue, Creep</td>
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<td>3D Modelling and Design</td>
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<td>Engineering Analysis of Software</td>
<td>Pneumatics and Hydraulics</td>
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<td>Model</td>
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<tr>
<td>Computer-aided Design and</td>
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<td>Manufacture (CADCAMP)</td>
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<th>5. WORKSHOP PRACTICE</th>
<th>10. ELECTRICAL/ELECTRONIC ENGINEERING</th>
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<td>Hand and Power Tool Operation</td>
<td>Terminology and Definitions</td>
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<td>Joining and Forming</td>
<td>AC, DC and simple circuits</td>
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<td>NC Machining</td>
<td>and Electric Motors</td>
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<td>Engineering Drawing</td>
<td>Digital Electronics and Microprocessors</td>
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<td></td>
<td>Transducers, Signals and Signal</td>
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<td></td>
<td>Processing</td>
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Table 2.2
Courses Content for Product and Industrial Design in UK cited in Myerson 1991, p. 27
2.3.3 Materials technology for this research agenda

Materials technology was selected from all other technologies for this research agenda basically due to the reasons below.

Materials technology is one of the technologies in which both ID and ED share an important emphasis on materials processes, materials selection, and materials properties. It was noted also, that 4 out of 10 technological contents mentioned in Myerson’s report (1991) for ID and product design education: materials, processes, workshop practice, and manufacturing are related to materials technology. Moreover, the additional technological contents which are required in completing the ED programme (item no. 8 and no. 9 in Table 2.2): engineering science and mechanical engineering are also related to materials science. This demonstrates that materials technology is indeed very important for ID and ED education and their practices.

Furthermore, there is a newly emerging agenda [implied by a number of scholarly papers from ‘Special Files’ in the Journal of the Faculty of Architecture, Middle East Technical University (METU) 2010] that seems to be overcoming the previous main emphasis on engineering aspects for a more balance approach between technical and sensorial properties. This can be also noticed from current sophisticated markets and demands of contemporary product design. The hedonic or expressive feel of product (as expressed by Pedgley, 2010); or aesthetics and emotional needs for products (as stressed by Ashby and Johnson, 2003), besides their functionality, has become quite an important aspect in determining the preferences of consumers.
The importance of balancing the engineering design aspects, industrial design aspects, including the user emotional needs has been seriously considered in design solutions amongst product designers, and associated awareness in the study of materials technology has been developed amongst design schools nowadays (if not at many institutions, at least Loughborough Design School, Industrial Design at METU, Department of Design Engineering at Delft University of Technology, Faculty of Industrial Design Engineering of the Technical University of Delft, and the Department of Chemistry, Materials and Chemical Engineering at Politecnico di Milano are extensively involved in research concerning this new agenda).

According to Ashby (2001; 2005), designing with materials, rather than materials ‘science’, helps ED students and practitioners in the structuring of criteria for selection. Thus, the integration of materials selection with other aspects of design, the relationship with stages of design and optimisation, and with the mechanics of materials are indeed essential throughout the designing processes (Ashby, 2001; 2005).

Whereas Ashby and Johnson (2004) disclose that ID student-designers and working designers are more inclined to visual thinking methods for choosing materials and processes to match the requirements of a product design; so, aesthetic appearance and information about the perceived value of materials and their application on products are required.

The selection of materials technology as the context of this research is a consequence of the emerged new understanding of materials and requirements of product design. Echoing that shifting emphasis in materials, visual tools used in approaching the context also seem to have progressed from typically ‘linear’ diagrams to more complex representations of the communication intended. Hence the choice of materials technology is a timely context for researching the VCT.
2.4 Visual Communication and Technical Information Design

From the perspective of educational communication, the purpose of teaching and learning is to deliver and obtain knowledge, skills and values. A collection of information is not knowledge as per se, it is simply data; nonetheless, when it has been processed and ‘understood’, it becomes knowledge, and at different levels of being ‘understood’, the knowledge is transformed into wisdom (Jarjis, 2007). A visual representation of these defined meanings is illustrated in Figure 2.10.

![Figure 2.10](image)

Relationship within communication planning, information design and the depth of data, starting from information, knowledge then to wisdom, adapted from Jarjid, 2007

In the context of this study in relation to Figure 2.10, context independent data relates to technological content e.g. materials. Communication strategies serve as methods to communicate technological data, e.g. for materials technology, so that relations concerning materials selection, processes and properties (technological information) can be understood.
When information design is applied to further enhance the technological information, and hence ease the understanding of its patterns, at this stage, the information design transformation is supporting its knowledge. After knowledge is gained, and the underlying principles understood, then wisdom is achieved. The stages of knowledge and wisdom, in reality, could be attained at varying levels.

NCSU\textsuperscript{3} website (2008) describes information design as the exploration of the cognitive, cultural and technological implications of visual, spatial and temporal strategies for the design of textual, pictorial, graphic and sound information. For this research the focus of information design being investigated is the communication outcomes of interactions among people and 2D representation. This has been selected for research because of its supposed links to cognitive modelling (see section 2.2).

It has been implied that visual elements are able to enhance the process of comprehending information (Ashby and Johnson, 2004; Baynes, 2009; Storer, Badni, Bhamra and Farmer, 2005; and many others). This statement suggests that the design of the visual information must empower the visual quality so that it could communicate and achieve certain universal agreement.

A common statistical computation (Figure 2.11) can be translated into a graphical display (Figure 2.12) for effective impact, making the data clear as explained by Tufte (2004, pp. 13-14). The common presentation of statistical information (Figure 2.11) comprises many technical details – numbers and descriptions, in this case.

The data is readable through the words and numbers shown. However, this does not provide visual support to help the reader to conceptualise or compare the overall context of the data.

\textsuperscript{3} North Carolina State University.
By depicting the same technical information in the form of visual elements (Figure 2.12), not only can the data be read easily in detail, but the characteristics of each data set are clearly displayed. The visual enables readers to visualise the variations for each data set and to compare important details. It is an immediate and concise form of information design, enabling points to be made clear and understood instantly.

The examples used for explanations so far are simple depictions. A far more complex form of visual could be necessary depending on the technological context. The point is that the preparation of visual depictions is a complex task. It involves thoughtful information design and planning.
2.4.1 Current understanding of combining visual and text – ‘information and instructional design’

According to Pettersson (2010), information design comprises two main components, infology (a theoretical component) and infography (a practical component). Infology is about the combination of verbal and visual presentation and interpretation of messages in order to communicate information; and which should be designed to facilitate communication from information producers to a group of receivers within learning processes (Pettersson 2010, p. 20). He also added that complicated language (texts and pictures) can easily impair the understanding of the message. Thus, designers of information should control effectively the key concepts of active voice, attention, clarity, comprehensibility, consistency, emphasis, information ethics, legibility, memory, perception, precision, processing, quality, readability, reading value, simplicity, structure, and unity in information design (Pettersson 2010, p. 20).

Subsequently, infography is the actual practice of design and the execution of structured combinations of words, pictures, and graphic design (Pettersson 2010, p. 20-21). Good information material should consist of comprehensible, clear and consistent texts and illustrations, which also include clear and transparent typography and layout that are able to aid attention, perception, interpretation, understanding and learning for the intended receivers (Pettersson 2010, p. 21). Therefore, to produce good information material, in line with Pettersson’s perspective (2010, p. 21), it requires a team of people with various relevant expertise to work together; besides the information designers needed to have theoretical knowledge and practical skills to structure our thoughts and describe them verbally.
An example of verbal and visual presentation that requires interpretations of messages in the perspective of computer science is a graph. ‘Graphs’ are often accompanied by text, which are categorised as linguistically coded information that is inclusive of graphical elements and verbal constituents (Acarturk, Habel and Cagiltay 2008, p. 335). According to Acarturk, Habel and Cagiltay (2008), this modal of representation is commonly the mode of communication in most learning information.

Pettersson (2010) provided a list of design principles and founded on research in various disciplines. Among their principles are the following.

Rowland (1993), after studying the process of design across a number of professions, included the following characteristics in his principles of a general process of design (cited in Pettersson 2010, p. 27):

1. **Designing requires a balance of reason and intuition, an impetus to act, and an ability to reflect on action taken.**
2. **The design process is a learning process.**
3. **Designing is a goal-directed process in which the goal is to conceive and realise some new thing.**
4. **The design process is dependent on the designer and on what he or she designs.**
5. **The new thing that results from designing has practical utility.**
6. **Design requires social interaction.**
7. **Designing involves problem solving, but not all problem solving is designing.**
8. **In designing, problem understanding and problem solving may be simultaneous or sequential processes.**
9. **Designing involves technical skills and creativity and rational and intuitive thought processes.**
Pettersson (2010, p. 27), from his own studies concerning processes of message design in 1993, established design principles for the production of information and instruction:

1. *Introduce novel or unexpected events at the start of instruction.*
2. *Inform learners of expected outcomes.*
3. *Recall relevant prerequisite information.*
4. *Present only relevant information.*
5. *Organise content and present ‘organisers’.*
6. *Progress from simple to complex.*
7. *Provide prompts and cues.*
8. *Vary the information presented.*
9. *Present examples and non-examples.*
10. *Provide appropriate practice.*
11. *Provide immediate feedback or knowledge of results.*

Pettersson (1997, pp. 110-118) also provided the principles of ‘functional message design’ for the presentation of clear messages in any medium, as the following:

1. *Facilitating learning*
2. *Providing a clear structure of the message*
3. *Providing clarity*
4. *Providing simplicity*
5. *Providing unity*
6. *Securing a high quality of the message*
7. *Limiting the total cost*
8. *Respect copyright*

9. *Information aesthetics*

10. *Harmony and proportion*

In addition to these principles, Pettersson (2010, pp. 33-34) added new information design principles for the purpose of presenting clear verbal and visual messages for any medium. The principles were put into four groups, as shown in Figure 2.13:

1. *Functional principles*

2. *Administrative principles*

3. *Aesthetic principles*

4. *Cognitive principles*

![Figure 2.13](Image)

The four groups of message design principles: Aesthetic Principles (red boxes); Administrative Principles (blue boxes); Cognitive Principles (yellow boxes); and Functional Principles (green boxes) cited in Pettersson, 2010, p. 34
Pettersson (2010) cited Smith and Ragan (1999, p. 7), who produced a ‘model of instructional design’ which consists of three phases:

1. **Analysis of the learning context: this includes analysis of learners, learning tasks, and writing of test items.**

2. **Development of organisational strategies, delivery strategies, management strategies, and production of the actual instruction.**

3. **Assessments and formative evaluation, which may lead to revision of the instruction.**

In order to produce ‘good instruction’ or as Pettersson (2010, p. 29) modified this term, to produce ‘good information design’, information design assumptions for the designer include the following:

1. **To design an information set, the designer must have a clear idea of what the user should understand as a result of using the information set.**

2. **The ‘best’ information set is that which is effective (facilitates users’ acquisition of the identified knowledge and skills), efficient (requires the least possible amount of time necessary for users to achieve the specified goals), and appealing (motivates and interests users, encouraging them to read, or listen to, the complete information set).**

3. **Many different media may be used for distribution of specific information content. Different media have their specific advantages.**

4. **There are principles of information design that apply across all age groups and all content areas. Users must be active rather than passive, interact mentally as well as physically with the information material.**

5. **Evaluation of information should include the evaluation of the information set as well as the evaluation of the user’s performance. Facts from these evaluations should be used to revise the information set in order to make it more efficient, effective, and appealing.**
6. **When the purpose of assessment is to determine whether users have achieved the goals, the users should be evaluated in terms of how nearly they achieve those goals.**

7. **There should be congruence among goals, reading, and assessment. Along with user’s characteristics and context, information goals should be the driving force behind decisions about activities and assessment.**

Lohr’s (1993, pp. 41-44) principles of instructional design and instructional message design were (cited in Pettersson 2010, p. 31):

1. **Figure/ground:** refer to the mind’s tendency to organise into figure and ground categories; thus, it is to make the most important information noticeable.

2. **Hierarchy:** is based on the mind’s tendency to process and remember ‘chunks’ of information that in turn are arranged hierarchically; thus, it is to shape the information structures to show subordinate, super-ordinate, and coordinate relationship.

3. **Gestalt:** comprises figure/ground and hierarchy principles, and is based on the belief that the whole is greater than the sum of its parts; thus, text and visual must be combined to present messages.

Lipton (2007, p. 9) provided information design principles as follows (cited in Pettersson 2010, p. 27):

1. **Consistency** (is there a design style sheet at work – for example, does one headline look like another?)

2. **Proximity** (does the amount of shape between elements reflect the relationship between the elements?)

3. **Chunking** (are related elements grouped and separated from others to make them digestible, instead of dauntingly unbroken?)
4. **Alignment** (does every element line up with some other one?)

5. **Hierarchy** (does the most important information look most important – placed at the top, bigger, bolder, or emphasised in some other way?)

6. **Structure** (is the information presented in a sequence that will make sense to the audience?)

7. **Balance and eye flow** (is there a clear starting place, and do the type and layout choices support the movement of your eye through the material?)

8. **Clarity** (is the writing clear and concise, free of unnecessary jargon or undefined terms, and at the right level for the audience?)

Pettersson (2010, p. 32-33) also cited Malamed (2009) who offered principles for creating graphics and visual language such as:

1. **Organise for perception:** “By understanding how viewers initially analyse an image, designers can structure and organise graphic so it complements human perception” (Malamed 2009, p. 45).

2. **Direct the eyes:** “A designer or illustrator can assist this process by purposefully guiding the viewer’s eyes through the structure of a graphic” (Malamed 2009, p. 71).

3. **Reduce realism:** “There are times when the ideal expression of a message can be achieved through visual shorthand. An effective way to do this is to reduce the realistic qualities embedded in a graphic” (Malamed 2009, p. 103).

4. **Make the abstract concrete:** “Visual thinking is an integral aspect of cognition, and the visualising of abstract concepts helps us understand the world and communicate about it” (Malamed 2009, p. 129).

5. **Clarify complexity:** Information is complex when it is voluminous, dense, and lacking in structure (Malamed 2009, p. 169).
6. **Charge it up:** The common assumption that art evokes emotion is reliably supported through brain research. When viewers look at both pleasant and unpleasant pictures, they consistently demonstrate an emotional reaction indicated by pronounced brain activity that does not occur when they look at neutral pictures (Malamed 2009, p. 203).

Amongst the established principles listed previously, some are specific to certain disciplines of design, and some are general. Researchers in those relevant areas are constantly adding to the list of principles. In fact, this research outcome could also contribute to these lists as contributing specifically to the understanding of the communication of technological information for the ID and ED. Nevertheless, the available principles from the different research areas have been included in order to facilitate making links and using them as building blocks where possible.

### 2.4.2 Reading images within the grammar of visual design

This section discusses some conceptual representations and structures of the reading images within the grammar of visual design. Although, some of the contents in this section, particularly semiotic modes that are more closely related to new perspectives on language, they could possibly contribute to visual communication and technical information design in some ways.

Kress and van Leeuwen (1999, p. 89) distinguished the ‘analytical processes’ as having two participants, which are related to parts (*Possessive Attributes*) and the whole (*Carrier*). ‘Carrier’ in this context, explained by Kress and van Leeuwen (1999, p. 49), represents the ‘whole’ (e.g. Australia), and a number of other participants; whereas, ‘passive attributes’ correspond to the ‘parts’ (e.g. the states of Australia).
They provided examples from abstract art which can be interpreted as having an analytical structure, e.g. *Pure Painting* from Theo van Doesburg (Figure 2.14), which they describe as having the structure of a map.

However, the highly abstract rectangles of different sizes and colours in the painting are not labelled as either *Possessive Attributes* or *Carrier*. This leaves the viewers able to interpret it themselves, and as a result, the painting can be read in many ways (Kress and van Leeuwen 1999, p. 92).
Conversely, an example of the map of a modern city (Figure 2.15), as selected by Kress and van Leeuwen (1999, p. 92-93), consists of green for recreational areas, yellow for housing, red for industrial areas, etc. By these concrete references or labels for colours, which have both Carrier and Possessive Attributes, this map is considered a schema that can be turned into a blueprint; therefore, it is an analytical structure of a representation (analytic visual), as analysed by Kress and van Leeuwen (1999, p. 93).

Kress and van Leeuwen (1999, p. 107) also provided examples of analytical image structures (Figure 2.16). This is potentially useful to relate to any design structure of the visual-technological-information (VTI) for visual communication of technology (VCT) in this research.

Within the structures (Figure 2.16), there are a number of process descriptors which could provide helpful analytical tools for the purpose of technical information design. They are as listed in Table 2.3.

![Figure 2.16](image)

Analytical Image Structures cited in Kress and van Leeuwen, 1999, p. 107
Kress and van Leeuwen (1999, p. 154) summarised interactive meaning as shown in Figure 2.17. The components that seem appropriate to technical information design are related to images that possess ‘objective attitude’, and which are action and knowledge oriented (the last component in Figure 2.17).

Table 2.3
Components in The Analytical Image Structures, adapted from Kress and van Leeuwen, 1999, p. 108

Kress and van Leeuwen (1999, p. 154) summarised interactive meaning as shown in Figure 2.17. The components that seem appropriate to technical information design are related to images that possess ‘objective attitude’, and which are action and knowledge oriented (the last component in Figure 2.17).
These aspects of orientations, according to Kress and van Leeuwen (1999), usually encoded in scientific and technical pictures such as diagrams, maps and charts. *Action orientation* is about encoded information in an exact view, where viewer position ‘as we see it’ from all sides of equal length (Kress and van Leeuwen 1999, p. 149). Whereas, *knowledge orientation*, as described by Kress and van Leeuwen (1999, p. 149), is about encoded information in perspectives, where viewer positions of ‘as we know it is’ through several positions of views, which have none equal dimension at all sides. These 2 depictions are as shown in Figure 2.18.

![Figure 2.18 Cube seen from only one aspect of 'objective attitude' of Action; and in an angle for Knowledge (Kress an van Leeuwen, 1999)](image)

Alternatively, Engelhardt (2006) proposed that exploring detailed terminology of visuals syntax can help to understand the analysis and comparison of visual representations. He provided a much more simple list of the nature of ‘ingredients’ for visual representations (visual syntax that applies to all graphics). They include: *objects; spaces; and properties*. The relationships and definitions of these visuals syntax, as defined by Engelhardt (2006, pp. 104-105) are:

- **Objects** may have different syntactic functions (e.g. a map or a chart is a graphic object, as well as symbols or components which positioned within that map or chart are also graphic objects); and that

- **Spaces** are constructed from basic ‘building blocks’ (e.g. a graphic space is the canvas or surface that is occupied by a graphic object); and an object may contain an internal space and sub-object that are arranged within that space.
- **Syntactic functions of objects** are node, connector, frame and label, which are useful for visual representations.

- **Properties** are referred to colour or size that used to complement graphic objects, so that they become meaningful.

Additionally, Kress and van Leeuwen (1999, p. 159) revealed that the crucial aspect of communication is linked to the reliability of messages, where to some extent the form of message itself suggests an answer. Modality in linguistics terms refers to the truth value or credibility of a statement about the world (Kress and van Leeuwen 1999, p. 160); whereas the role of colour was classed by Kress and van Leeuwen (1999, p. 165) as a marker of naturalistic modality in these scales:

- **Colour saturation**, a scale running from full colour saturation to the absence of colour (which is to black and white).

- **Colour differentiation**, a scale running from a maximally diversified range of colours to monochrome.

- **Colour modulation**, a scale running from fully modulated colour, with, e.g. the use of many different shades of red, to plain (un-modulated colour).

- **Contextualisation**, a scale running from the absence of background to the most fully articulated and detailed background.

- **Representation**, a scale running from maximum abstraction to maximum representation of pictorial detail.

- **Depth**, a scale running from the absence of depth to maximally deep perspective.

- **Illumination**, a scale running from the fullest representation of the play of light and shade to its absence.

- **Brightness**, a scale running from a maximum number of different degrees of brightness to just 2 degrees: black and white, or dark grey and lighter grey, or two brightness values of the same colour.
Baynes (2010, p. 19) offered a parallel example, which is that “good vision was also instrumental in cognitive and even philosophical developments, providing the ‘big brain’ with a significant visual world full of stimulus and meaning.” Baynes added that this specially associated with “depth perception that defines a 3D space filled with movable solid objects. Colour makes objects pop out from their backgrounds, and gives us sensation that corresponds to the stuff the object is made of, distinct from our perception of the stuff,” Baynes (2010, p. 19) cited from Pinker (1977).

In a similar manner to Kress and van Leeuwen’s (1999) idea of colour, Baynes (2010) provided another instance of those modes or aspects that could not be communicated or modelled through language and number. ‘Colour’ is one of those, based on Baynes’ (2010, p. 19) analysis, as it provides immediate understandable examples, where it can only be discussed or evaluated by reference to actual examples or models. Although one might argue that colours can be described in terms of their wavelengths as a part of a cataloguing system, a particular tone or hue cannot be consciously perceived or evaluated without a visual reference used as guide for comparison to see their slight differences (Baynes 2010, p.21).

For example, can the exact ‘Red’ colour be described, in terms of its tone and hue, if it was not by displayed with its actual visual references, as shown in Figure 2.19 below?

![An Exact Visual Reference of A Series of Pantone Red Colours](image)
‘Proportion’ shares similar impossibility for perception except by actual visual reference to itself. Baynes (2010, p. 21) elaborated that proportion “can be expressed numerically and to some extent described in words, but the example has to be presented in actuality, as a model or in the imagination, before it can be appreciated or manipulated.”

The Golden Section diagrams (Figure 2.20) were given as examples by Baynes (2010, p. 20) to illustrate that the impact of visual representation on our senses and consciousness are far more comprehensible and appreciable, beyond the descriptions using language to give instruction on how to construct the figures, and using numbers for the expression of their mathematical properties.
This expression was also supported by Ferguson (1992), as cited in Baynes (2010, p. 21):

“Certainly it is very difficult to transmit through the medium of natural language or scientific notation knowledge of certain sorts of dextrous skill or sensory discrimination, or to render into natural language adequate equivalents of, say, musical notation or engineer’s orthographic drawings of mechanisms.” (Ferguson, 1992)

Other physical properties, aesthetic qualities and spatial relations that are difficult (or impossible) to convey in natural language, provided by Baynes (2010, p. 21) include:

- Colour
- Space
- Form and shape
- Movement
- Structure
- Distance
- Proximity
- Texture
- Pattern
- Spatial relationships
- Scale
- Proportion
- Visual rhythm
2.5 Principles and Techniques for 2D Visual Practice

There are many credible experts in the area of graphics (or VC) who have established good guidelines, principles and even techniques for the purpose of developing good sources for the means of communication. For example, there are Tufte’s (2004, p. 77) principles of graphical integrity for the display of quantitative information:

1. The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.

2. Clear, detailed, and though labelling should be used to defeat graphical distortion and ambiguity. Write out explanations of the data on the graphic itself. Label important events in the data.

3. Show data variation, not design variation.

4. In time-series displays of money, deflated and standardised units of monetary measurement are nearly always better than nominal units.

5. The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.


Pettersson (2010, p. 25) also highlighted that there have been many design principles offered in different areas of design. The areas he identified included data graphics\(^4\), general design\(^5\), message design\(^6\), instructional design\(^7\), instructional message design\(^8\), and information design\(^9\) (some were in broad and general perspectives, but some were specific).

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\(^4\) Tufte 1983, p. 105  
\(^5\) Tufte, 1983; Shadrin, 1992; Rowland, 1993  
\(^6\) Pettersson, 1993, 1997; Wileman, 1993  
\(^7\) Lohr, 2003; Smith and Ragan, 1999, 2005  
\(^8\) Fleming and Levie, 1993  
\(^9\) Pettersson, 2010
Pettersson’s conclusion was that the process of message design is guided by the message design principles (as illustrated in Figure 2.19), and which should be performed with message design tools at an early stage for the development of a suitable type of representation. This is in order to achieve the effective and efficient message design for information and learning materials (Pettersson 2010, p. 25, 43). The relationships within the components in Figure 2.21, as described by Pettersson (2010) are:

“There are many models for design processes. It starts with a commission (C). The goal is to produce a final design (D), to be used as a master for production of a number of representations (R) or artefacts. Design processes are guided by design principles and performance with the help of design tools and always influence by the social context.” (Pettersson 2010, p. 43)

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Figure 2.21
Design Processes are guided by Design Principles cited in Pettersson, 2010, p. 43)

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9 Petterson, 2002, 2007; Lipton, 2007
Other considerations of the visual methods are referred by Paley (2008). He emphasised that visual richness (e.g. beyond just colour to texture, varying line widths, curving lines; even pseudo-3D edge, drop shadows, and a node shape that suggest their meaning) can be either added just to excite the eye or to help the visual parsing of the images, the layering of the information, and to act as a visual mnemonic: easing the mental connection of glyph and idea. He proposed that in order to produce effective complex representations of abstract data, the creator of the visual information should carefully consider data structure and mental mechanisms of vision and cognitive science (Paley 2008, p. 2). Not distorting data to be a distracting illustration, instead folding more data into the images by respecting the visual processes we engage to decode it, would make the data representation clear, so that it becomes easy to process and reach the stage of understanding (Paley 2008, p. 3).

2.6 The Emergent Principles of VCT

The key emerging principles of VCT are derived from Tufte (1990; 2004; 2006) who provided a range of comprehensive principles and techniques to develop effective quantitative and statistical graphical visual information; Rand (1971; 1985) who gave perspectives on graphic design for persuasive visual communication; Ferguson (1993) who presented the history of engineering design and visualisation tools; and Thomson (1979) who offered graphic principles for engineers. The VCT principles that emerged were based on the common elements from these authors.
Edward Tufte has been described by the New York Times as the “da Vinci of data” and by Business Week as the “Galileo of graphics.” He has written, designed, and self-published four books on visual thinking and analytical design: The Visual Display of Quantitative Information (1983; 2001; 2004), Envisioning Information (1990), Visual Explanations (1997), and Beautiful Evidence (2006). These books have received 40 awards for content and design and have 1.8 million copies in print. It was announced in March 2010 that Barack Obama was to appoint Tufte to the American Recovery and Reinvestment Act’s Recovery Independent Advisory Panel, to explain how the money from the President’s economic stimulus package is to be spent (IQ² Global, 2010).

Paul Rand, a well-known American graphic designer, was best known for his corporate logo designs. Rand’s education included the Pratt Institute (1929-1932), the Parsons School of Design (1932-1933), and the Art Students League (1933-1934). He was one of the originators of the Swiss Style of graphic design. If the word ‘legend’ has any meaning in the graphic arts and if the term legendary can be applied with accuracy to the career of any designer, it can certainly be applied to Paul Rand (1914-1996). He was an outstanding cover designer for Apparel Arts and Directions, and was cemented his international reputation and identified him as a designer of influence from Zurich to Tokyo (Area of Design, 2002).
Eugene S. Ferguson (1916-2004) was an engineer and historian of technology. After holding a number of engineering positions in manufacturing he moved into engineering education and then the history of technology. In 1977 his frequently cited paper on visual reasoning appeared in the Journal Science. Ferguson later expanded its themes into a book, Engineering and the mind’s eye. Ferguson was a founding member of the Society for the History of Technology and its eleventh president (1977–78). The Society recognised Ferguson’s contribution by creating the Eugene S. Ferguson Prize for Outstanding Reference Work (Eugene, 2010).

Robert Thomson’s Principles of Graphic Communication for Engineers is an example of a straightforward guide for graphic communication for engineering drawing, and it was among the early publications in the 80s that was used for that purpose. Other similar publications could have been selected.

Tufte’s (1990; 2004; 2006) principles, perspectives and techniques for good graphical practice are as indicated in Figures 2.22 and 2.23 (reference of visuals see Appendix 2.4). He highlighted, “graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space; it is nearly always multivariate; and it requires telling the truth about the data” (Tufte 2004, p. 51). He also added that “graphical excellence consists of complex ideas communicated with clarity, precision and efficiency” (Tufte 2004, p. 51). Tufte (1990; 2004; 2006) provided many visual examples for each of his graphical principles and techniques. Figure 2.24 is one of his many visual analyses that tell a lot of information in a very fine structure.
### Escaping Flatland:
- giving perspectives, 3D model, different dimension and indications of information, including symbols, icons, etc. to enrich the density of data display.

### Micro/Macro Readings Of Details

#### Layering And Separation Of Data
- Small Multiples (multiples in space and time):
  - reveal repetition and changes, pattern and surprise – the defining elements in the idea of information
  - direct depiction comparison – the essence of statistical thinking (enforce local comparison within our eyespan relying on an active eye to select and make contrast)
  - enhance the dimensionality of the flatlands of paper and computer screen – giving depth of vision by arraying panels and slices of information
  - create visual lists of objects and activities, nouns and verbs – helping viewers to analyse, compare, differentiate and decide (encourage visual reasoning of seeing, distinguishing and choosing)
  - represent and narrate sequences of motion
  - amplify, intensify and reinforce the meaning of images

### Colour And Information

### Narrative Of Space And Time

### Sparklines

### Links And Causal Arrows:
- provide summaries of evidence about specific character of relationship
- arrows, links and other connectors should be more articulate, more differentiated but less generic
- should be carefully used as these diagrammatic links and arrows usually assume too much and explain too little – could create ambiguity
- are good techniques for trees
- links can be scaled linking lines, colour-coded links, multiple classification of colour links, typographical symbols (&,*), marginal annotation

### Coherence Of Words, Numbers And Images (Proportion and scale of):
- line weight and lettering
- shape of graphics

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**Figure 2.22**
Principles of Graphical Excellence (Tufte 2004, p. 13), reference of visuals see Appendix 2.4

**Figure 2.23**
Perspective and Techniques for Good Visual Information (Tufte 1990; 2006)
reference of visuals see Appendix 2.4

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### Tufte’s Principles of Graphical Excellence:

1. **Show the data**
2. **Induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphic production or something else**
3. **Avoid distorting what the data have to say**
4. **Present many numbers in a small space**
5. **Make large data sets coherent**
6. **Encourage the eye to compare different pieces of data**
7. **Reveal the data at several levels of detail, from a broad overview to the fine structure**
8. **Serve a reasonably clear purpose: description, exploration, tabulation or decoration**
9. **Be closely integrated with the statistical and verbal descriptions of a data set**
Rand (1985, p. xiii) revealed that, “graphic design is essentially about visual relationships, providing meaning to a mass of unrelated needs, ideas, words and pictures. It is the designer’s job to select and fit this material together, and make it interesting”. Once the visual relationship of information has been clearly displayed, the mind’s employment will function to discover meaning (Rand, 1985), Figure 2.25a. Additionally, visual information should attain the embodiment of form and function (Figure 2.25b); together, they integrate beauty and function in order to persuade and inform through visual communication (Rand 1985, p. 3), Figure 2.25c.
Rand’s (1971) principles of graphics for visual communication are:

- Balance and contrast reveal the relationship
- Visual depiction (graphics) should carry relevant meaning or message of actual subject
- Co-operate as an instrument in the service of communication
- Provides the means of clarifying, synthesizing, and dramatizing a word, a picture, a product, or an event

Ferguson (1993) recorded the historical engineering evidence of visualisation tools, which have been used widely and significantly to complement innovation, engineering design, and development. Some tangible and commonly known examples are visual tools such as pictorial perspective, orthographic projection, and graphic symbols used in engineering drawings. Based on Ferguson’s (1993) argument, sketches also play significant roles in effective communication throughout, and complement engineering innovation.
He elaborated that the ‘Thinking Sketches’ (Figure 2.26) helped the inventor or designer to focus and guide in nonverbal thinking and to clarify vision in their mind’s eye during observing and designing processes (Ferguson, 1993). ‘Perspectives Sketches’ (Figure 2.27) aided the communication between engineer and drafter in order to guide the drafter in completing the engineering drawing (Ferguson, 1993).
‘Talking Sketches’ (Figure 2.28) supported constantly the exchanges of ideas between technical people for any further improvement during the construction (Ferguson, 1993). Hence, visual thinking or modelling in the mind’s eye can be seen to be becoming a key aspect of designing and communication processes of innovation and technologies.

To ensure visualisation tools empower positive visual impact for readers, Ferguson (1993) also emphasised the following key focuses in Figure 2.28 that it is to:

- Show relative comparison of scale (Figure 2.29)
- Illustrate how a device/machine operates or is being used (Figure 2.29)
- Produce engineering drawings (Figure 2.32), models (Figure 2.31) and visual analysis tools (Figure 2.30)
- Provide precise dimensions and shapes (Figure 2.32)
- Illustrate exploded and extended views of devices/machines to inform details about assemblies, etc. (Figure 2.30)
- Form a visual structure that functions as mathematical system (Figure 2.33).
The drawn image on the left not only illustrates the look of the machine, but also provides information about the operation, function and size by comparing the relationships between the human figure and the machine. Whereas, the image on the top only inform how the machine looks like.

Figure 2.29
Drawing of a Sawmill Machine
(Perspective view of manually driven up-and-down sawmill from Jacques Besson’s pioneering machine book *Theatre des instrumens mathematiques et mecaniques* cited in Ferguson, 1993, p. 79)
Figure 2.30
Exploded and Extended Drawing of a Ratchet Device, da Vinci 1500 [Leonardo’s ratchet device of c. 1500 is shown assembled (at left) and ‘exploded (at right) cited in Ferguson, 1993, p. 88]

Figure 2.31
Harvard teaching apparatus, 1765-1900s: Mahogany stand with pulleys and weights demonstrating principles of Newtonian mechanics cited in Ferguson (1993, p. 144)

Figure 2.32

Figure 2.33
Visual Emphasis: Nomogram, A Mathematical System, Maurice d’Ocagne 1862 (Nomogram used to calculate the brake horsepower of an engine being tasted with a Prony brake cited in Ferguson, 1993, p. 151)
Thomson (1979) noted that graphic information used to communicate among engineers and related personnel must be completely clear, precise and provide straightforward information. Every detail and fundamental geometry, methods and principles of presentation, and proper dimensioning must be well applied (Thomson, 1979). He emphasised that functional drawing, a simplification, which must be free from unnecessary views and details, avoiding artistry and repetition, and making full use of symbols and conventions must be used to communicate with the readers (engineers) of known ability.

Thomson’s (1979) principles of graphic communication for engineers are:

- Avoid artistic elaboration (Figure 2.34a)
- Do not draw unnecessary views (Figure 2.34b)
- Do not redraw repetitive details (Figure 2.34c)
- Describe in words or provide dimensions when necessary (Figure 2.34d)
- Do not show hidden details unless they are required for clarity (Figure 2.34e)
- Omit unnecessary details from assembly drawings
- Symmetrical objects should be drawn as a fraction of the whole wherever possible (Figure 2.34f)
- Fullest use should be made of graphical symbols and conventions, particularly in fluid, electrical and electronic circuits (Figure 2.34g)

The visual samples of the mentioned principles are as shown in Figure 2.34 from (a) to (g).
So, Ferguson (1993), Rand (1971; 1985), Tufte (1990; 2004; 2006) and Thomson (1979) emphasised different aspects and various purposes of VC, but ultimately they revealed common ground for excellent VC of information. Key principles of VCT therefore emerged based on those common perspectives. Namely, the representation’s capability in facilitating comparison to reveal connections and relationships; unity of form to accentuate function; precision of data to communicate accuracy or truth; and all graphical structures should be simple in design form, but complex in carrying data, in short, the key emerging principles (KEPs) of VCT are:

1. **COMPARE > RELATIONSHIP**

2. **FORM > FUNCTION**

3. **PRECISE > TRUTH**

4. **SIMPLE IN DESIGN > COMPLEX IN DATA**

Figure 2.34
Visual Samples of Thomson’s Principles of Graphic Communication for Engineers cited in Thomson (1979, pp. 72-73)
Each of these VCT principles can be elaborated in relation to two different concerns:

- Technical and technological matters
- Graphic arts.

### 2.6.1 Principle 1 (KEP-1): COMPARE > RELATIONSHIP

- Facilitating comparison to reveal connections and relationships for the concern of VCT; and in parallel
- Displaying visual relationships to engage the mind in discovering meaning for VC.

Ferguson (1993) provided examples that focused and guided nonverbal thinking, clarified vision in the mind’s eye, and showed relative comparison (Figures 2.26-2.30).

Tufte (2004) encouraged the eyes to compare different pieces of data, so that the data at several levels of detail was revealed, providing a broad overview with a fine structure (Figure 2.24).

Similarly, Rand (1985) emphasised that visual representation must demonstrate relationships in order for the viewers to make links, and subsequently, to balance and contrast help in displaying relationships. Kouwenhoven (1982, p. 208) emphasised that “where we perceive no pattern of relationship, no design, we discover no meaning,” this is because “apparently unrelated things become interesting when we start fitting them together...in that the mind’s characteristic employment is the discovery of meaning, the discovery of design” (as cited in Rand 1985, p. xiii). Thus, Rand (1985) concluded that graphic design is essentially about visual relationships (Figures 2.25a-c).
Thomson (1979) highlighted only displaying relevant details in order to avoid confusing the clarity of relationship (Figure 2.34b). Likewise, Pettersson (1993, cited in 2010, p. 27) highlighted “present only relevant information” and “provide prompts and cues” in his principles for the production of information and instruction.

Lipton (2007, p. 9) also emphasised proximity in terms of whether “the amount of shape between elements reflect the relationship between the elements” in her information design principles. This is also about using elements for the purpose of calling attention for connectivity and relationships.

2.6.2 Principle 2 (KEP-2): FORM > FUNCTION

- Unity of form as in visual representation to accentuate function or to support innovation/design decision making (in VCT matters); and in parallel
- Integrating beauty (form) and function for both persuasive and informative tools for communication in the area of VC.

Ferguson (1993) recorded some examples of visual structures that functioned as mathematical systems to achieve particular calculations and generalisations. They were Cartesian coordinates (17th Century), graphical statics of a force polygon10 (19th Century), and nomograms11 (end of 19th Century) (Figure 2.33).

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10 Force polygon is a graphical construction that is made to predict relative force in the members for a given loading of the structure. The advantages of this graphical statics are qualitative, presenting in the calculations a sense of “what’s going on” – a “feel” – and permitting the engineer to build in the mind’s eye a vision of the force in a complex structure (Ferguson 1993: 150).

11 Nomogram is another visual mathematical technique that brought together a number of specialised graphical methods to solve particular mathematical equations and develop a generalised approach (Ferguson 1993: 151-152).
Tufte (2004) emphasised that a graphical representation should present many numbers in a small space and make the data set coherent. Additionally, they should serve a reasonably clear purpose in description, exploration, tabulation or decoration in order to amplify, intensify and reinforce the meaning of images (Tufte, 2004) (Figure 2.24).

Rand (1985) revealed that the embodiment of form and function is to integrate beauty and usefulness in both persuasive and informative visual communication. He also emphasised that graphic design co-operates as an instrument in the service of communication, and uses comprehensible images to translate abstract ideas into concrete forms (Rand, 1971), Figure 2.25b.

Thomson (1979) stressed that functional drawing is a simplification, making the fullest use of symbols and conventions and reduced to the barest essentials for users of known competence. However, if it was oversimplified, uncertainties may occur and hence a drawing can be misread (Figures 2.34g).

The above aspects and views are also of similar to Lohr’s (1993) principles of instructional design and instructional message design, in terms of:

1. *Hierarchy*, where “it is to shape the information structures to show subordinate, super-ordinate, and coordinate relationship” (cited in Pettersson 2010, p. 31).

Which is about forming a structure by several things at various levels, and to function as a visual format that allow viewers to make connection, so as relationships in within those visual elements would be made sense of.

2. *Gestalt*, which is “based on the belief that the whole is greater than the sum of its parts; thus, text and visual must be combined to present messages” (cited in Pettersson 2010, p. 31).

This implies that, by using elements of graphics to form a holistic unity, one is able to accentuate the function of providing messages.
2.6.3 **Principle 3 (KEP-3): PRECISE > TRUTH**

- Precision of details to communicate the truth/accurate information or story for the concern of VCT; and in parallel

- Visual depiction should carry relevant meaning or message of the actual subject/content in the concern of VC.

Ferguson (1993) noted that the historical evidence of thinking sketches and engineering drawings were those that communicated precise information between engineer, drafter, and facilitated the exchange of ideas between technical people (Figures 2.30 and 2.32).

In addition to the Principles of Graphical Excellence noted earlier, Tufte (2004) highlighted two other Principles of Graphical Integrity: 1) representation of numbers (physical measure on the graphical surface) should be proportional to numerical quantity represented; and 2) clear, detailed and precise labelling system (providing necessary explanations and/or important events) should be applied to defeat graphical distortion and ambiguity (Figure 2.24).

Rand (1985) revealed design should provide “a means of clarifying, synthesizing, and dramatizing a word, a picture, a product, or an event” (p. 233), and implied visual depiction should carry relevant meaning or message of the actual subject (2.25c).

Thomson (1979) stated that graphics for engineers must be in a complete story, conveying precise and positive information on shape, size of every detail, and describing exactly every operation necessary for realization (Figure 2.34d). Subsequently, the presentation must be clear and in a straightforward manner.
2.6.4 **Principle 4 (KEP-4): SIMPLE DESIGN > COMPLEX DATA**

Besides those three principles, visual representation must be *simple* in design form; but *complex* in carrying data/information. Tufte (2004) determined that well-designed data graphics are usually the simplest and the most powerful methods for analysing and communicating statistical information.

Rand (1985) highlighted that simplicity implies not only an aesthetic ideal, but a meaningful idea, either of content or form, that can be easily recalled.

Thomson (1979) stressed not drawing unnecessary views; and not redrawing repetitive details and hence keeping a simple form.

This emphasis is stressed also by Pettersson (1993) that to "*progress from simple to complex*" in his principles for the production of information and instruction; and "*providing simplicity and unity*", which were related to his (Pettersson, 1997) principles of functional message design for the presentation of clear messages in any medium.

The following sections 2.7 and 2.8 (research on diagrammatic representations, and eye-tracking as research tool) are included in this literature review chapter. Even though they are not seen as part of the research context (diagrammatic representation relate rather more to cognitive psychology and computer science studies; and eye-tracking could be regarded as a research method), research relating to them could be useful in supporting the discussions of VCT, examinations and articulations of the KEPS described in the previous sections. However, the details of eye-tracking as a research method and its suitability will be further discussed in Chapter 3, and its detailed application and operation will be explained in Chapter 6.
2.7 Research on Diagrammatic Representations

Many of us are familiar with diagrams since our schooling because they are used within academic activities across the curriculum (this can be also traced in Danos’s findings of graphicacy used across curricula, 2009). To some of us, we even might consider it as compelling forms of representation (if this does not relate to you, at least it was to the author’s personal experiences of the use of diagrams, which helped her to remember many key points of certain subjects’ content, instead of memorising the linguistic text).

Likewise, Barkowsky (2010, p.1) identified diagrams as a powerful form of knowledge representation for both spatial and non-spatial problems. He distinguishes two forms of mental spatial-analogical representations in terms of ‘spatial mental models’ and ‘visual mental images’ (Barkowsky 2010, p.1), as follows:

- **Spatial mental models**: refer to abstract representations which focus on specific structural aspects of spatial relationship.

- **Visual mental images**: are concerned with much more complete and more detailed representations.

From Ferguson’s (1993) point of view through analysing historical evidence of engineering design related to visual representations:

“The information that the drawings convey is overwhelmingly visual: not verbal, except for notes that specify materials or other details; not numerical except for dimensions of parts and assemblies. Such drawings, resulting from nonverbal thinking and processing the ability to transfer visual information across space and time, are crucial role as intermediaries of engineering thought.” (1993, p. 5)
Problem-solving by reasoning through language and numbers is familiar. However, Stieff, Hegarty and Dixon (2010) took a step further by suggesting using diagrams (an external visual representation) for spatial reasoning. They suggested that “the use of algorithms or heuristics can allow the problem solver to complete these tasks by abstracting spatial or non-spatial information from internal and external representations” (Stieff, Hegarty and Dixon 2010, p. 115). In one of their findings imagistic strategies (e.g. mental rotation and perspective taking) relies on spatial information given in the external diagrams.

In the experiment of the effect of graphs’ examination on recall capability, Paoletti and Rigutti (2008) found the following:

- Readers who examined the graphs as compared to those who did not, were demonstrated to have better recall.

- Graphs that have related text placed close to each other allowed better recall for readers as compared to those graphs that were placed far away from the related text [this also supported by Mayer (2001), concerning the \textit{spatial contiguity effect}].

- When text and graphs were integrated (rather than visualising the graphs within a pop-up window) the evidence suggested better recall among the readers.

Although the above experiment was done through digital format (on a computer screen), the author believed the findings were as meaningful and useful to printed formats, if the text and graphs integration is being examined. In fact, there were also many similar research studies in these areas of texts-graphs or texts-images relationships. Examples include:

- Pictures help students in comprehending hard concepts and facilitating information acquisition (Peeck, 1987; Brody, 1982; Schallert, 1980; Levie and Lentz, 1982), since both verbal and visual form of information allows for dual coding (Paivio, 1986; Mayer, 2001; Hegarty and Carpenter, 1991; Carney and Levin, 2002).
• Positive impact of pictures within texts on recall and comprehension of content (Alesandrini, 1984; Peeck, 1987; Paivio, 1986; Mayer, 2001).

• Text and graphs in a separated condition engage readers to search for the corresponding figure, causing the cognitive load to be excessive and hence the possible reduction in comprehension and the effectiveness of the recall system (Chandler and Sweller, 1991).

2.8 Eye-Tracking as Research Tool

The eye-tracking method has been possible for over fifty years; however, it is only the recent advancement of technology that has made the eye-tracker devices commercially feasible as research tools; and the device allows a close examination of the conscious and unconscious gaze movement of a respondent in visual system research (Eyetracker, 2010; System-concepts, 2010; Wikipedia, 2010).

An operation of a visual system starts from eye movements, and these movements can be linked to perceptual systems; it is their close relation to attentional mechanisms, saccades that can provide insight into cognitive processes, e.g. language comprehension, memory, mental imagery and decision making (Richardson and Spivey 2004, p. 2).

Therefore, the eye movements’ research became a great interest in the study of psychology and cognitive neuroscience, cognitive linguistics, ergonomics, advertising and design (Richardson and Spivey, 2004; Eyetracker, 2010; System-concepts, 2010; Wikipedia, 2010).

The visual system research in the areas of advertising and design are commonly focusing on the consumers’ behaviour, particularly on commercial messages for products. This can be supported by Richardson and Spivey (2004, p. 17) as they suggested that eye-movement behaviour of consumers can determine immediate perceptual factors and decision-making processes.
Richardson and Spivey (2004, p. 15) cited early empirical findings from Perky (1910), Clark (1916), Stoy (1930), Goldthwait (1933) and Totten (1935) that the frequency of eye movements increases during mental imagery. In addition, their recent work suggests that eye movements are engaged by both memory of specific perceptual experience and cognitive acts of imagination (Richardson and Spivey 2004, p. 15). Levy-Schoen (1983, p. 66) emphasised, “to the extent that eye movements are reliable correlates of the sequential centring of attention, we can observe and analyse them in order to understand how thinking goes on.”

The use of eye-tracking on design-based research works by Fischer et al. (1989), Pieters et al. (1999), Russo and Leclerc (1994), Malach et al. (2005), and many other works reported in Jacob and Karn (2003, pp. 582-584) were based on these similar grounds of eye movements and perceptual systems.

According to Josephson (2000, p. 64), an eye-tracker device records three main kinds of precise information such as:

1. **Fixation frequency**: is the total number of fixations a viewer makes on an area of the visual field;

2. **Fixation duration**: is summing the length of individual fixation (measured by millisecond), when viewer looks at a specific visual area; and

3. **Fixation sequence**: is the hierarchical mapping that records the order in which a viewer scans the visual information.

Subsequently, she cited from Krause (1982) that the above three measurements correspond to the following three critical assumptions, which are:

1. The eyes fixate on the information currently being processed;

2. The fixation time of an item is directly proportional to the processing time; and

3. The eye-fixation sequence corresponds to the sequence of processing.
Eye-tracking data has been accepted as one of the most valid measurement methods for visual information, and these were based on 3 widely accepted propositions of Fischer et al. (1983), reported by (Josephson 2000, p. 64):

1. Fixations accumulate in locations judged to contain high semantic or visual information;
2. Fixations are responsible for perception and are generally considered as a reflection of the individual's cognitive strategy; and
3. Fixation sequence allows for the encoding, storing, and subsequent reconstruction of the images.

Additionally, Jacob and Karn (2003, p. 584-585) reported that based on 21 research studies using the eye-tracking method, the common matrices used were:

1. Number of fixations (on an overall visual)
2. Gaze % (proportion of time) on each area of interest
3. Fixation duration mean (on an overall visual)
4. Number of fixations on each area of interest
5. Gaze duration mean on each area of interest
6. Fixation(s) rate (on an overall visual)

Indicators of each of the above matrices provided by Jacob and Karn (2003, p. 585) are:

1. Number of fixations (on an overall visual): A large number of fixations indicates less efficient search possibly resulting from a poor arrangement of display elements.
2. Gaze % (proportion of time) on each area of interest: The proportion of time looking at a particular display element (the interest area) could reflect the importance of that element. Duration reflecting difficulty of information extraction; and frequency reflecting the importance of that area of the display (Fitts, et al., 1950).
3. Fixation duration mean (on an overall visual): Longer fixations (or longer gazes) are generally believed to be an indication of a participant’s difficulty extracting information from a display (Fitts, et al., 1950; Goldberg and Kotval, 1998).

4. Number of fixations on each area of interest: The number of fixations on a particular display element (the interest area) should reflect the importance of that element.

5. Gaze duration mean on each area of interest: Gazes on a specific display element would be longer if the participant experiences difficulty extracting or interpreting information from that display element.

6. Fixation(s) rate (on an overall visual): This matrix is closely related to fixation duration. Since the time between fixations (typically short duration saccadic eye movements) is relatively small compared with the time spent fixating, fixation rate should be approximately the inverse of the mean fixation duration.

Jacob and Karn (2003, p. 585) also suggested that other promising and important eye-tracking matrices but that are seldom being considered in researchers’ studies include:

1. Scan path (sequence of fixations) and transition probability between area of interest – which can indicate the efficiency of the arrangement of elements in the user interface.

2. Number of gazes on each area of interest – are often more meaningful than counting the number of individual fixations, because of the concentration of successive fixations within the same area of interest.

3. Percentage of participants fixating an area of interest – can serve as a simple indicator of the attention-getting properties of an interface element.
4. *Time to 1st fixation on target area of interest* – is a useful measure when a specific search target exists.

Barkowsky (2010, p.1) emphasised that eye movements can be used to resemble the perceiving of real visual stimulus if operating on visual-mental-images; whereas, while operating on spatial-mental-models, the structure of mental representation and the eye gaze patterns produces no correspondence. Therefore, human reasoning processes (whether involved mental-models or mental-images) and which aspects are in focus during the mental-images processing can be traced through eye movements.

The aspect of focus in mental-images processing can be further examined in the way that Hegarty (2006, p. 13) suggests of eye fixations are coded and analysed in terms of ‘visualisation of the data to gain a general understanding of the patterns of fixation’ and derivation of quantitative methods from the data (statistical analyses).

Example of quantitative measures which can be drawn from using eye-tracking analyses, given by Hegarty (2006, p. 14), in terms of examining the usage of meaningful entities (e.g. the legend in a graph, a component of a machine, a particular region of space in a map) are:

- Gaze duration on regions of interest (ROIs) in the diagram at different stages of task performance.
- Number of fixation on different ROIs at different stages of task performance.
- Number of transitions between different ROIs.
- Sequence of fixating different ROIs.
Hegarty (2006, p. 14) also suggests that eye-tracking methods should be of use to cognitive psychology, education, human-computer interaction, information visualisation, software developmental areas of research, and analysis of spatially distributed data, because eye responses would be involved in all those disciplines.

Through an eye-tracking experiment (an eye-gaze control behaviour) on a ‘table information reading’, Shimojima, Katagiri and Enseki (2010, p. 325-327) found that readers’ attention was first spread over a large-scale object (entire column of an alphanumerical table which consisted of a few figures); and later multiple fixations were placed on an individual row of figures. These results, according to them, can help in finding out ‘how people set boundaries to graphical objects to be interpreted’ and ‘how they maintain the object boundaries during the given task’. By tracking down these two problems, the way people comprehend information graphics can be discovered (Shimojima, Katagiri and Enseki (2010, p. 325), and hence this can help in graphics planning in terms of the hierarchical layout of information and graphical elements.

The above reviews can be a useful guide for the design of data collection methodology for this research, particularly, the research intention of gathering the reading-patterns and message-perceptions of visual information; and the effectiveness of the applied visual communication of technology (VCT) on those visuals. The data will help to trace the eye movements involved during reading and comprehending technological visual information. Nonetheless, the aspect of capturing the perception would be accompanied with conventional methods of questionnaires and interviews. Both the relevant aspects of eye-tracking and conventional methods will be introduced specifically in Chapter 3 and discussed further in Chapter 6.
2.9 Summary: Key Issues Emerging from Literature Review

This section summarises the key issues emerging from the literature reviews in this chapter, with the intention of providing some highlights and anticipations toward the explorations, investigations and discussions for the rest of this thesis.

Section [2.1] Technology as the summation of ‘Knowledge’, ‘Skills’ and ‘Values’ in design education was taken as the principle of technological aspects and competencies for course contents and activities. Subsequently, the technological concepts within these competencies were assessed in terms of:

- **Control, Energy and Materials** for the competency of ‘Knowledge’
- **Investigation, Invention, Implementation and Evaluation** for the competency of ‘Skills’
- **Technical, Economic, Aesthetic and Moral** for the competency of ‘Values’
The use of VC has been significant since early human developments of technologies, and has been researched for many decades.

Many claims were made concerning the associations of the use of VC in delivering and communicating ‘knowledge’ within designing processes i.e. that it stimulates the mental (internal) and physical (external) modelling ‘skills’, and therefore contributes to creativity and innovation capabilities (‘values’). These were assertions without supporting empirical evidence.

Creativity is a sophisticated ‘values’ and often too subjective to be defined and measured.

ID and ED were traced with differences in expressions of visual formats and specific ‘skills’ needed for different requirements of product- or content-based enquiries; however, the usage of visual representations remained the same for ideations (‘knowledge’) and innovation (‘values’).

Materials technology was identified as one of the most important technologies shared between ID and ED education and actual practice.

Materials selection is a timely issue to be explored in both the educational field and the practical world in relation to the new approaches of balance between technical and sensorial properties for improved ‘knowledge’, ‘skills’ and ‘values’ contributions.
Section [2.4] Theoretical and structural VC guidance were gathered.

Section [2.5] Many significant and established principles, techniques and good guidelines are available for 2D VC materials for information and learning purposes.

None are available specifically for technological contexts which are required to carry more complex and sophisticated issues in a single representation.

Section [2.6] Key principles for VCT emerged from a number of experts’ guidelines and common foci.

Section [2.7] Many theoretical diagrammatic approaches and research concerning their effective use in cognitive psychology and computer sciences were studied.
Section [2.8]  
Eye-tracking as a tool to trace eye movements on visual representations and to the extent whether readers comprehended the information and the time taken for understanding were studied and provided with evidence in many cases.

However, the studied visual representations were rather simple in structure or were studied in a single aspect (e.g. a line-graph or an annotation arrow in the graph, an illustration integrated with a body text, a pulley rotation, etc. and these were not representative of the more complex visuals necessary for communicating technological issues.
Chapter 3  Research Plan

Chapter Overview

Chapter Three discusses the overall plan of this research and describes the approach, design frame and methodologies undertaken throughout the research data gathering. It explains the role of triangulation, corroborative evidence and a mixed research methods strategy, and how these provided evidence to explore the research questions. It also discusses the issues of achieving reliability and validity of the research findings. Figure 3.1 illustrates how Chapter Three fits into the structure of this thesis.

Figure 3.1  Chapter 3 in the Structure of Thesis
3.1 Research Principles and Approach

The research programme starts with a number of broad purposes, and these lead to the development of research objectives and questions that guide the overall conduct of the research enquiry. Literature reviews and a series of three main case studies are the key components for the empirical research agenda. The principles and approach to this research are discussed below.

3.1.1 The strategy, reliability and validity

After establishing the research objectives and questions relating to each objective, a strategy based on multiple levels of triangulations was plotted throughout the research programme. Each of the research questions was initially explored through literature reviews. From these reviews, a decision was to be made as to whether a further investigation was needed; or whether the available literature already answered that particular research question well enough.

Where there was insufficient evidence from literature reviews, other methods of data collection would be considered in order to attain further support of evidence. Within this strategy, the researcher would ensure that there was a total number of at least three supporting sources (a triangulation approach) inclusive of the literature review and another two methods of data gathering to be conducted for the purpose of obtaining corroborative evidence, illustrated in Figure 3.2.

It is considered reliable research if the measuring instruments are consistent throughout, and obtain the same results in several testing. However, this is an ideal instance according to Thomas (2010, p. 105), which is not so practical in applied social science student research (as it is not like psychometrics situation). Reliability in applied social science environment, to Thomas (2010, p. 106), should be far more important to focus on whether “the instrument is doing what you want it to do and is not picking up something irrelevant.”
The strategy of applying triangulation in order to gain corroborative evidence was the effort and intention undertaken to achieve reliability. In this, each aspect of the research study was being viewed and tested from three directions, with the aim of the findings or results from these three approaches supporting one another to reach a conclusion to one study.

Validity, on the other hand, means the extent to which the instrument (or a test) measures what it is supposed to be measuring; and which, particularly a construct validity, is where “the results of a test (or another instrument) correlate with the theoretical construct for which it is seeking to act as an assessment” (Thomas 2010, p. 107).

Consequently, beside the triangulation, this research study was planned to have validation study (could be of any form of method) as an additional integration to the research programme in order to validate the overall outcomes of the triangulation (Figure 3.3). Table 3.1 illustrates the strategy of identifying data collection methodologies for this research; ultimately, this strategy illustrates the principles underlying the research project.

![Figure 3.2: Triangulation, Corroborative Evidence and Reliability](image)
Figure 3.3  
Validation of Triangulation
## Chapter 3: Research Plan

### Objectives

1. **Objective-1:** To investigate the principles behind the communication of technology, predominantly the general visual communication of technological information.

2. **Objective-2:** To explore the learning of technology through visual communication and achieving creativity and innovation in designing.

3. **Objective-3:** To explore and evaluate existing visual communication tools or resources for industrial and engineering design teaching and learning environments.

### Research Questions

1. What is visual communication?
2. How is visual communication used to communicate knowledge of technology?
3. What are the links between visual communication of technology, designing, creativity and innovation?
4. What is industrial design (ID)?
5. What is engineering design (ED)?
6. What are the technological information requirements for ID and ED?
7. What are the effective methods for visual communication of technological information?
8. How is visual communication used to communicate technological information to ID and ED student designers in higher education around the world?

### Research Strategies

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<tr>
<th>Literature Review</th>
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<th>CS2</th>
<th>CS3</th>
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<td><strong>Main source</strong></td>
<td><strong>Subsidiary source</strong></td>
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**Table 3.1:** Research Strategy for Identifying Data Collection Methodologies
This strategy seems appropriate for the following reason, and also other reasons described in the next few sections:

“Sometimes people are tempted to think of types of research first (quantitative or qualitative) and then think of research pathway that will lead to one of these. This is entirely wrong: your research approach should be the servant of your research question, not its master. Always start with your research question, and think of ways of answering it. This may lead you to a design frame where you use numbers, or it may lead to one where you use words. The important thing is that you use the design frame that is right for your question...” (Thomas 2010, p. 83)

3.1.2 Triangulation and corroborative evidence

Triangulation is about collecting information from a diverse range of individuals and settings, using a variety of methods (Clare 2001, p. 75). When more than one method is used in collecting data, Denzin (1978) specified it as methodological triangulation. Thomas (2010, p. 111) expands Denzin’s categories of triangulations by adding design frame triangulation to represent different types of design frame being used in the same piece of research.

Robson (1993, p. 383) expresses that triangulation is an ‘indispensable’ tool and particularly ‘valuable’ for qualitative data analysis. Likewise, Thomas (2010, p. 111) views triangulation as seeing things from several points of view, and which is better than viewing from one direction. For this reason, he stresses that alternative kinds of evidence provide a good chance for one to corroborate the other, and therefore, make the findings even more powerful (Thomas 2010, p. 112).

Based on these perspectives, design-frame-triangulation and methodological-triangulation have both been adopted while establishing the prospective plan for this research. A macro-triangulation (represents the design-frame-triangulation) is first aimed at achieving the three research objectives, shown in ‘Design Frame/Strategy’ section, Figure 3.4 (or an enlarge version in Figure 3.5).
Chapter 3 Research Plan

Research Design

Research Purposes
- Visual communication of technology (VCT)
- Claims of VCT supporting designing and stimulating creativity and innovation
- Criteria that help the development of VCT
- Technologies in ID & ED
- Cultural concerns: Malaysia and the UK; ID and ED
- Improvement of visual tools for ID and ED education

Research Objectives & Questions

Objective 1
- RQ1
- RQ2

Objective 2
- RQ3

Objective 3
- RQ4
- RQ5
- RQ6
- RQ7
- RQ8

Model of Analysis

Literature Reviews

Qualitative
- Qualitative

Quantitative
- Quantitative

Design Frame/Strategy

VCT > Designing > Creativity

KEPs of VCT

VCT within a Context

Data Collection Methodologies

Literature Reviews (LR)
- Validation Study
- Case Study-1
- Kite-designing (LDS, UK)
- Kite-designing (PIS, Malaysia)

LR: KEPs of VCT
- Validation: 16th Century vs. current practice analysis
- Case Study-2
- Kite-Poster Design
- Eye-Tracking Kite-Poster

LR: VCT in Context
- Experts Discussion
- Case Study-3
- Books Analysis
- VTIs analysis, redesign & survey

Figure 3.4
An Outline of Research Design
(adapted from Process of Research Design cited in Thomas 2010, p. 92)
Each aspect of the macro-triangulation featured another cycle of micro-triangulation (representing the methodological-triangulation), shown in the ‘Data Collection Methodologies’ section, Figure 3.4 (or an enlarged version in Figure 3.2).

Evidence could be potentially frail or weak. In either case, different ways of gathering it would be a useful solution, because one piece of evidence could support the other (Thomas 2010, p. 18). By this instance, triangulation is ideally an approach for the purposes of gathering several types of evidence. Therefore, by triangulation, either in terms of design frame (the macro aspect) or methodologies (the micro aspect), corroboration of evidence would be evolved for reliable outcomes of data gathering. With an additional round of validation study (in any form of method e.g. a case study, a comparative visual or scientific analysis, and/or an expert’s views), its data would further validate the overall triangulation outcomes, and lead to an improvement of quality and accuracy of the research project findings.
However, when we come to the stage of interpreting the corroborative evidence, there will be two possible ways of either ending with a conclusion or suggestion. For instance, if three evidences from the triangulation and the evidence from the validation study all pointed to the same direction, it means there will be a conclusion to be drawn upon. Instead, if the corroborative findings from the triangulation and the validation study obtained different results, then suggestions for further research might be a possible solution.

3.1.3 Mixed methods

Mixing design frames and methods is regarded as acceptable, and in fact, it is to be applauded as long as researchers can keep the selected methods in the research project timeframe. “…say, a survey, an experiment and a case study all in the same research project…different elements of your research, relates to different questions, will almost certainly need different methodological responses from you.” (Thomas 2010, p. 140)

Robson (1993) and Thomas (2010) shared similar views in research methods, and there were these 3 traditional research strategies which might seem possible and suitable for this research, are outlined as follow:

- **Experiment**: is about measuring the effects of manipulating one variable on another variable (Robson 1993, 40); an investigation of some kind or a trial of something; or in a social research (a rather precise perspective), it is about demonstrating cause and effect; and it concerns the extent to which we have to control the conditions in the situation of interest to demonstrate that cause and effect relationship (Thomas 2010, p. 124).
• **Survey**: is about collection of information in standardized form from groups of people (Robson 1993, 40). It involves data collection from a varied number of respondents, and it includes various data gathering methods within them, e.g. from a questionnaire, interview or some kind of diary entry. Additionally, these data are collected to describe features of a social situation in which they exist, not a manipulated feature of situation as they would be in an experiment. The collected descriptive data can be examined for the existence of relationships between and among them (Thomas 2010, p. 135).

• **Case study**: is about development of detailed, intensive knowledge about a single ‘case’, or of a small number of related ‘cases’ (Robson 1993, 40). It involves an in-depth research into one case or a small set of cases; in which it aims to gain a rich detailed understanding of the case by examining aspects of it in detail. The collected data can be from different facets of the question we are examining and perhaps it could from numbers or from interviews or informal observations; or may be a combination of all mentioned to tell a finished story (Thomas 2010, p. 115).

Within this study, it is felt that a mixture of purpose driven methods are best suited to attaining answers to the research questions, just as Thomas (2010) and Robson (1993) suggested.

Review of literature, on the other hand, is considered another method of survey for information gathering. It not only aided the gaining of existing knowledge in related topics to the research areas, but also provided a useful consensus concerning the research foci and context, and guided the initial stage of building up the research framework and methodology. Likewise, Thomas (2010, p. 30) generalises, by stating that even assuming that the researcher has convinced about the precise and do-able research questions, literature review would still lead to some paths that help to define more exactly what to do, which ultimately, will enable the research questions to be refined.
The review of literature also suggests the research methods as either qualitative or quantitative. The main characteristics of the qualitative research study are its descriptive nature of reporting, its focus on the social processes taking place as well as outcomes where its use of induction derive meaning (Punch, 2006). Therefore, the interpretive research is concerned with the meanings, or interpretations, placed on events by various participants. The research design of this study will be primarily descriptive and interpretative, analyzed and interpreted through a combination of exploratory and qualitative methods. While quantitative research usually involves numbers, formulas and statistics, it will also be of assistance to this research study in analysing some findings from the case studies.

Presentations at conferences were also used to reflect on research tools, methods and instruments alongside of this research. Papers were presented and later published in relevant research publications. Experts from various backgrounds of relevant disciplines helpfully reviewed, discussed and refereed the research. This feedback from experts, ultimately, led to modification to the conduct of the research, as well as to supporting validation of the appropriateness of the research tools, methodologies and instruments, and also some parts of the research findings.

In the perspective of cognitive psychology, non-quantitative or non-scientific research may be easily open to postmodernist critiques in terms of its credibility, reliability and validity of methods and data evidence. However, in current new conception of research, there is no ‘one way’ of understanding a certain knowledge or ‘one way’ of doing an inquiry (Thomas 2010, p. 141). Also, there are no ‘right’ or ‘wrong’ ways of going about research enquiries; rather, it is about *bricolage* (‘do-it-yourself’ or ‘means-at-hand’), as long as the methods seem appropriate and best to answer the research questions (Thomas 2010, p. 142-143). Quality interpretative and descriptive evidence can be also empirical, and thus qualitative research method has since been recognised worldwide.
3.2 Research Design

Figure 3.4 summarises an overall research plan and design. Research purposes lead to research objectives and questions, and these guided the inquiry to the overall research agenda. The literature provide a useful consensus position for building up the research framework, context and methodology, as well as establishing the key emerging principles (KEPs) of VCT to be further explored. The research questions are addressed via a number of research methodologies, which were first trialled in pilot studies for further improvement and maximizing their usefulness, before they were applied in the actual surveys and case studies. The three main case studies were selected in order to answer the research questions; and a triangulation approach was applied for corroborative evidence of data gathering, so as to achieve reliability and validity of findings. Finally, empirical data was interpreted and conclusions reached based on a combination of qualitative and quantitative analysis.

3.2.1 Design frame in this thesis

This section will discuss the macro triangulation aspect of the overall research project. It begins with the series of three case studies selected as the design frame in order to gather data concerning various aspects of the impact of the VCT (see Figure 3.5).

Case Study-1 is about exploring links between the VCT, designing and their associations to creativity and/or innovation. Posters, which were used in communicating technological knowledge of kite and other kite-making resources, were provided during a kite-designing exercise among a group of student designers in Loughborough Design School (LDS). This activity ends with the evaluation of creativity embodied in the students’ kite-design outcomes. A comparative study (to complete the Case Study-1 triangulation) was designed to be conducted in Malaysia, where the outcomes of this research programme are potentially to be implemented.
A further validation case study was carried out among PGCE trainees in LDS. It was to validate the overall triangulation findings. In the validation study, kite-information was narrowed down to that which had been shown to be the most preferred source i.e. kite-posters (detailed design of this case study will be further described and explained in Chapter 5).

Kite-designing incorporates many aspects of science and technology (as identified by scientists Ito and Komura, 1983). The kite-designing tasks provided opportunities for acquiring technological knowledge behind the making and flying of kites, modelling and designing processes, which would result in a designed outcome. According to Thistlewood (1990), genuine designing involves some level of creativity. This case study enabled a complete process (processing visual-technological-information/the posters to designing process, and then to measuring the levels of creativity of the outcomes) to be tracked and measured. Therefore, it is an ideal exercise to be selected as the research project to gather empirical data of the assertion made over the centuries (from literature reviews) about the links of VCT, designing and creativity or innovation.

**Case Study-2** is concerned with the detailed investigation and articulation into the aspects or criteria for the VCT when taken out of a specific context. The design and redesign of posters applying VCT were tested through an eye-tracking device. The device was used to objectively measure and trace reading paths from participants in order to compare to their perceptual strategies. The investigation used examples of good practice from the 16th Century, to compare with recently useful visual examples identified through literature reviews. This analysis of the 16th Century versus current good practice visuals helped to further validate the eye-tracking outcomes concerning the application of the KEPS in the kite-posters (detailed design of this case study will be further described and explained in Chapter 6).
The eye-tracking experiments allowed the KEPs of VCT derived from literature describing the intentions of the originators of the visuals to be validated against the interaction as experienced by a reader. The eye-tracker allows the researcher to find out whether what a person sees and has understood can confirm the effectiveness of certain visuals, particularly for those where there is evidence that they represent good practice, either in the past (the 16th Century) or in current situations.

**Case Study-3** concerns the placing of VCT within a context, so that its impact and the KEPs developed for creating and reading images can be articulated and further studied in a richer setting. Models and visual representations from two materials books (Ashby and Johnson 2004; Ashby 2005) are analysed; selected diagrams and illustrations from those books and also scholarly papers related to materials technology (METU, 2010) were analysed and redesigned based on the KEPs of VCT established from the literature survey. The outcomes of these analyses and redesigns were then put into the form of a questionnaire in order to conduct a survey. This third case study was designed to attain further validity for the KEPs of the VCT through comparison with the previous two case studies. A wider group of respondents, from different regions were targeted in order to also explore the role that cultural issues might play in the VCT. The views of experts were sought on the results of this case study in order to provide appropriate micro-validation. The detailed design of this case study will be further described and explained in Chapter Seven.

These VCT analyses within a context, in this case *Materials Technology*, allow further articulation of the KEPs to be explored and examined. Materials technology was selected from among the possible technologies because it plays an important role in industrial and engineering design. Additionally, it was also due to the current increasing interest among designers and users in searching for hedonic or expressive feel in contemporary product design.
Education and research in this context seems to be changing from placing its main emphasis on engineering aspects to a more balanced approach between technical and sensorial properties. With regards to this change, the visual tools used in representing and approaching the context also seem to have moved from typically ‘technical and linear’ diagrams to more complex representations.

3.3 Data Collection Methodology

This section will discuss the micro-triangulation aspect within the macro-triangulation. It is about the methodological triangulation, which is to gather data from three different perspectives for the purpose of corroborative evidence in regards to each of the case studies (Data Collection Methodologies section in Figure 3.4 as a summary). The three case studies were designed to answer the research questions and these relationships are shown in Table 3.2, which outlines the methodological triangulation within the three case studies.

3.3.1 Methodologies corresponding to the research questions

Table 3.2 outlines the research questions alongside the research data collection methodologies employed.
1. **What is visual communication (VC)?**
   1.1 The meaning of visual communication
   1.2 The importance of visual communication
   1.3 Are there graphical techniques or principles for effective visual communication?

2. **How is VC used to communicate knowledge of technology?**
   2.1 Are there effective visual communications of technology (VCT)?

### Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is visual communication (VC)?</td>
<td>• Visual literacy and visual language</td>
</tr>
<tr>
<td>1.1 The meaning of visual communication</td>
<td>• Visual communication principles and techniques</td>
</tr>
<tr>
<td>1.2 The importance of visual communication</td>
<td>• Information and instructional design</td>
</tr>
<tr>
<td>1.3 Are there graphical techniques or principles for effective visual communication?</td>
<td>• Statistical information design</td>
</tr>
<tr>
<td>2. How is VC used to communicate knowledge of technology?</td>
<td>No further findings were required because all these issues were resolved very well</td>
</tr>
<tr>
<td>2.1 Are there effective visual communications of technology (VCT)?</td>
<td>through literature reviews, which included many works conducted by experts and</td>
</tr>
<tr>
<td></td>
<td>academics around the world.</td>
</tr>
<tr>
<td>• Historical reviews in engineering communication</td>
<td>• Present technological content in posters form</td>
</tr>
<tr>
<td>• Graphic principles for engineering</td>
<td>• Test the effectiveness of communication via posters</td>
</tr>
<tr>
<td>• Analyse books on materials technology for ID and ED students.</td>
<td></td>
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</tbody>
</table>

Table 3.2 continues next page...
<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 How were visual methods used to communicate technology in the past?</td>
<td>• Technical communication in the past and present.</td>
</tr>
<tr>
<td></td>
<td>• VC and information design principles and techniques</td>
</tr>
<tr>
<td></td>
<td>* Evidence of successful and widely use of visual tools in communication of technologies way back in history; but not much practice in current states.</td>
</tr>
<tr>
<td></td>
<td>* Found of principles of VC; KEPs of VCT were then established.</td>
</tr>
<tr>
<td>2.3 How are visual methods used to communicate technology at present?</td>
<td>• Design technological-content-posters applying KEPs of VCT established from LR.</td>
</tr>
<tr>
<td></td>
<td>• Evaluate KEPs’ application via eye-tracking case study, which analyses readers’ reading patterns (eyes scanning paths and mapping sequence) while reading VTIs.</td>
</tr>
<tr>
<td></td>
<td>• Compare eye-tracking analysis with readers’ perceptions and comprehension of VTIs.</td>
</tr>
<tr>
<td>2.4 Which critical success factors, criteria, principles and/or techniques are important to determine appropriate VC?</td>
<td>• Analyse and compare visual tools used in the 16th Century and those in current practice.</td>
</tr>
<tr>
<td>2.5 Can those principles and techniques of VC apply to VCT?</td>
<td>• Analyse &amp; redesign existing VTIs used in materials technology books and scholarly papers, applying KEPs.</td>
</tr>
<tr>
<td></td>
<td>• Questionnaire survey to gather empirical evidence (qualitative and quantitative) on KEPs’ application.</td>
</tr>
<tr>
<td></td>
<td>• Assessment based on readability of visual and comprehension of information by ID and ED students from different cultural background: level of education and studied areas; countries.</td>
</tr>
<tr>
<td>2.6 How is appropriate or effective visual technological information (VTI) designed?</td>
<td>• Present papers at a number of conferences.</td>
</tr>
<tr>
<td></td>
<td>• Discuss and get feedbacks from visual literacy, design and technology (D&amp;T) experts; to validate/modify (where necessary) LR, research tools, methodologies and findings.</td>
</tr>
</tbody>
</table>

*Evidence of successful and widely use of visual tools in communication of technologies way back in history; but not much practice in current states.

Further enquiries are needed to answer issues and questions raised.

Found of principles of VC; KEPs of VCT were then established.

Table 3.2 continues next page...
<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
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</table>
| **3.** What are the links between VCT to designing, creativity and innovation?     | • Nature of technology for design  
• Modelling and designing  
• Creativity and innovation in education  
  * Many claims of VC support designing and trigger creative and innovative skills.  
  * No empirical evidence support the assertions made.  
  * Further enquiries are needed for empirical evidence.  |
| 3.1 What are the roles of technology in the process of design?                     | • Gather evidence from case study that linked the process of accessing VTI, designing-task and evaluation of creativity in a designing workshop.  
• Gather perceptions and interpretations of VTI used in the designing-task via questionnaire survey.  |
| 3.2 What are the factors to determine VTI play a role of stimuli to encourage creative and/or innovative skills in designing? | • Design and redesign kite-VTI, based on KEPs, findings from Case Study-1 and analysis of visual tools from the 16th Century and current time.  
• Analyse readers’ visual perceptions and comprehension on the VTIs from the 16th Century and current practice. This includes readers describe how those VTIs inspired them, and how they’d use the VTIs for their design ideas generation.  |
| 3.3 Are there evidence showing VCT support designing, and hence facilitate creativity and innovation? | • Present empirical findings at a number of conferences.  
• Discuss and get feedbacks from visual literacy, D&T experts; to validate/modify (where necessary) LR, research tools, methodologies and findings.  |

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<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. <strong>What is industrial design (ID)?</strong></td>
<td>• The meaning of industrial design and engineering design</td>
</tr>
<tr>
<td>4.1 What are the main characteristics of ID?</td>
<td>• The technologies for ID and ED education in the UK and Malaysia</td>
</tr>
<tr>
<td>5. <strong>What is engineering design (ED)?</strong></td>
<td>• Aesthetics, associations and perceptions of contemporary product design</td>
</tr>
<tr>
<td>5.1 What are the main characteristics of ED?</td>
<td>• New emergent agenda of materials technology in ID and ED</td>
</tr>
</tbody>
</table>

No further findings were required because ID and ED differences and the technologies associated were identified very well through literature reviews, which included many works conducted by experts and academics around the world.
<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7.</strong> What are the effective methods for visual communication of technological information?</td>
<td><strong>7.1</strong> What are the conventional methods for visual communication of technological information for ID and ED?</td>
</tr>
<tr>
<td>• Conventional materials books for ID and ED</td>
<td>• Conventional materials books for ID and ED</td>
</tr>
<tr>
<td>• New approaches for materials technology and its representations used to communicate the design aspects and its technological processes</td>
<td>• Analyse and compare KEPs application between visual tools from the 16th Century and those in current practice.</td>
</tr>
<tr>
<td>• Diagrammatic representation and inference</td>
<td>• Eye-track and check readers' eyes scanning patterns and perceptions in relation to the KEPs intention, so that to validate effective ways of communicating technological information.</td>
</tr>
<tr>
<td>* Assertions of ID required different models of representations then ED for comprehension; but, there is no empirical evidence was found.</td>
<td>* Analyse books on materials technology for ID and ED students.</td>
</tr>
<tr>
<td>* Further evidence is needed to answer issues and questions raised.</td>
<td>* Identify styles and representational models, graphical strategies, graphical techniques and KEPs of VCT.</td>
</tr>
<tr>
<td></td>
<td>* Analyse, redesign and survey the effectiveness of VTIs communication among ID and ED students.</td>
</tr>
<tr>
<td></td>
<td>* Present empirical evidence to experts and discuss the results and expectation.</td>
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</tbody>
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Table 3.2 continues next page...
### Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Research Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. <strong>How is visual communication used to communicate technological information to the ID and ED student designers at higher education around the world?</strong></td>
<td>8.1 <strong>Is there any cultural difference in VCT?</strong></td>
</tr>
<tr>
<td>• Statistical information and instructional design principles</td>
<td>• Lecturers’ feedbacks concerning difficulties in delivering complex theories of materials; thus, looking for possible visual tools to assist teaching.</td>
</tr>
<tr>
<td>• Diagrammatic representation and inference</td>
<td>• Test on reading poster and diagrams: to identify their comprehension.</td>
</tr>
<tr>
<td><strong>Haven’t found the relevant empirical evidence, but claims are asserted.</strong></td>
<td>• Questionnaire survey to indentify whether technological information can be well communicated through VCT.</td>
</tr>
<tr>
<td><strong>Further studies are needed to answer issues and questions raised.</strong></td>
<td><strong>VTIs analysis and redesigning using KEPs.</strong></td>
</tr>
<tr>
<td></td>
<td>• Questionnaire survey to identify the impact of VTIs readability and comprehension from 3 higher institutions from 3 different countries.</td>
</tr>
</tbody>
</table>

Table 3.2
Research Questions with Related Data Collection Methodologies
3.3.2 **Eye-tracking application as method**

The eye-tracking method is an important component in the methodologies used to experiment and gain evidence for the research project. Thus, it is partly discussed in this section (detailed methodology and its application onto this research case studies are further explained in Chapter 6).

Many research studies in the advertising and design fields have used eye-tracker techniques to gather extensive data and have provided important findings for the improvement of the presentation for the marketing purposes. The eye-tracking allows a large amount of statistical data concerning eye movements to be obtained. However, Jacob and Karn (2003) emphasised that some common details e.g. scanning path, number of gazes, percentage of participants fixating an area of interest, and time to first fixation on target area of interest were interesting measures for research, but that they have often been overlooked during analysis in many studies.

The uses of eye-tracking methods have made possible the close examination of the conscious and unconscious gaze movement of a respondent in research concerning visual systems (Eyetracker, 2010; System-Concepts, 2010). The human visual system starts with eye movements, which are linked to perceptual systems; it is the close relationship of these movements to attentional mechanisms, saccades that can provide insight into cognitive processes, e.g. language comprehension, memory, mental imagery and decision making (Richardson and Spivey 2004, p. 2).

The eye-tracking metrics (Table 3.3) could provide useful guidelines for evaluating reading-patterns of visual information; and subsequently, the effectiveness of the applied VCT principles on the studied visuals.
For this research study, these types of eye-tracking data (in Table 3.3) have greatly been considered in tracking the eye movements involved during reading and comprehending visual technological information. The aspect of capturing the message-perceptions associated with the visual information was accomplished using the conventional research methods of questionnaires and interview prompts.

### 3.3.3 Quality of data collections

The data from the considered methods (by eye-tracking device, questionnaires and interview prompts) could be seen as qualitative, which addresses issues by acting in real-time and assessing the relationship between the respondents and the visual subject. Similarly, Blalock (1970) and Robson (1993) identify these methods as addressing questions of “what people did and what they say they did”.

<table>
<thead>
<tr>
<th>Visual Descriptions</th>
<th>Impact Indication</th>
<th>Language Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+)</td>
<td>1. Frequency of gaze (number of fixations) on each area of interest &gt; reflect the importance of that area/element of display.</td>
<td></td>
</tr>
<tr>
<td>(+)</td>
<td>2. Scanpath (sequence of fixations) and transition probability between areas of interest &gt; can indicate the efficiency of the arrangement of elements in the visual surface.</td>
<td></td>
</tr>
<tr>
<td>(-)</td>
<td>3. Duration of fixation (gaze duration) &gt; longer fixations reflect difficulty in extracting information from display.</td>
<td></td>
</tr>
<tr>
<td>(-)</td>
<td>4. Number of fixations (at overall visual surface) &gt; reflect poor display of visual elements.</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3

Eye-Tracking Metrics (adapted from Jacob and Karn 2003; p.585; Josephson 2000, p. 64)
This is also related to Rowan and Huston (1997, p. 1442) that “designed to observe social interaction and understand the individual perspective, provides insight into what people’s experience are, why they do, what they do…” Angrosino (2007); furthermore, notes that qualitative research tend to explore and analyse data capture from the people experiences, interactions and communications by subjects within the observation settings, and the related documents (e.g. diaries, audio and/or video recordings). Thus, specific information concerning eye movement (would be captured by eye-tracker video) in corresponding to the brain processing and understanding information (would obtain via recording of audio within interview prompts) would be perfect for obtaining qualitative data.

At different stages of the research case studies, questionnaires surveys are mainly incorporated in order to attain quantitative measures to possibly generalise the findings (detailed explanation will be included in related chapters of case studies). This is trying to avoid Morgan’s (2008, p. 798) concerns of lacking potential for generalisation by only having qualitative descriptions and interpretations. The advantages of a quantitative approach is its measure of the reactions of many people to a limited set of questions, hence facilitating comparison and statistical aggregation of the data so that a generalisable set of findings can be presented succinctly and parsimoniously (Patton 2002, p. 14).

Consequently, the plan of using both qualitative and quantitative methods in analysing and interpreting data and findings is as Ke (2008) indicates by using quantitative method in corresponding to qualitative techniques which would establish a substantial body of evidence resulting from the triangulation of data.
3.4 Sampling and Selection

Loughborough University and Politeknik Ibrahim Sultan (to represent Polytechnics Malaysia) are the two main venues for research data collections. The research is being mainly assisted and conducted in Loughborough Design School (LDS); and Polytechnics Malaysia, who are sponsoring the research and where the outcomes will be directly implemented.

Moreover, both higher institutions offer industrial design (ID) and engineering design (ED) programmes to students of age range between 18 to 25 years, and that equally match the research subject and context. However, other higher institutions of a few regions also participated in the questionnaires survey due to their interest of the area of research.

Allison et al. (1996) and Thomas (2010) list many types of sampling commonly used in research studies. They include simple random sampling, systematic sampling, stratified sampling, cluster sampling, quota sampling, stage sampling, convenience sampling, purposive sampling, and dimensional sampling.

Due to the nature of this research, the student participants in Malaysia for most of the case studies or survey were mainly a purposive sample in that they represent students in particular categories, which are ID and ED. They could also be described as a convenience sample as they are a captive audience of students of materials class. Student participants in LDS (either ID or ED) and other institutions in other countries, on the other hand, are also a purposive and convenience sample, as well as captive audiences as same as described above (ID and ED group in materials class) for some case studies. Additionally, there are also some volunteers for some of the questionnaire surveys.
3.5 Research Instruments

Sources of information and instruments are:

- Literature reviews
- Students designing workshops
- Creativity evaluation sections
- Eye-tracking experiment
- Individual interviews
- Own design and redesign practice
- Questionnaires surveys (lecturers and students)
- Experts group interview and discussion

Table 3.4 outlines the sources used to explore and answer the research questions:
<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Instrument/Information/Activity</th>
<th>Sample</th>
<th>Type of Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CASE STUDY-1: The Link between VCT &gt; Designing &gt; Creativity and Innovation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Finding of claims of the link</td>
<td>• Literature reviews (LR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 2. Kite-designing-task                | • Sources of information to assist designing (actual kites, materials for kite-making, internet links for kite information, kite-VTI)  
  • Designing workshop                  | • 145 LDS ID Students  
  • Purposive & convenience                                                                 |                               |
|                                       | • Students kite-design outcomes                                                                                       |                               |                        |
|                                       | • Creativity analysis guideline and tools: (1) Thistlewood’s (1990) designing models; (2) Paired-comparison check slips  
  • Questionnaire for preferred source |                               |                               |                        |
| 3. Comparative study in Malaysia      | • Same as the above; including  
  • Questionnaire for delivery of materials technology (lecturers)                                                          | • PiSID (24) and ED (24) students  
  • PiSID and ED Lecturers               | • Purposive & convenience                                                                                       |
| 4. Validation study group             | • kite-VTI                                                                                                            | • 30 LDS PGCE Trainees        | • Convenience           |

*Table 3.4 continues on next page...*
<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Instrument/Information/Activity</th>
<th>Sample</th>
<th>Type of Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CASE STUDY-2: KEPs of VCT (A Non-Contextual Analysis)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Finding of VC principles; established KEPs of VCT</td>
<td>• Literature reviews (LR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Kite-Poster/VTI design and redesign</td>
<td>• KEPs of VCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Existing kite resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Findings from Case Study-1 for design improvement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Eye-tracking analysis on kite-VTI</td>
<td>• Eye-tracker device</td>
<td>• 3 PhD students from ID background</td>
<td>Purposive &amp; voluntary</td>
</tr>
<tr>
<td></td>
<td>• Own design practice: Kite-VTI (Poster)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Validation: Analysis of the 16th Century and current visual representations using eye-tracker</td>
<td>• Eye-tracker device and workstation, laptop, audio recorder, projector, table lamp</td>
<td>• 5 PhD students (background of education: 1-Design and Technology; 1-Materials Sciences and Engineering; 1-Art and Design/Fine Art; 1-Industrial Engineering; 1-Industrial Design.</td>
<td>Purposive &amp; voluntary</td>
</tr>
<tr>
<td></td>
<td>• PowerPoint slides for all the visuals</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Semi-structured questions to guide interview prompts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Some personal details, cultural, educational background information and conscientious form, following Loughborough University’s ethical guidelines.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 3.4 continues on next page...*
<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Instrument/Information/Activity</th>
<th>Sample</th>
<th>Type of Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Finding of differences in ID &amp; ED; emergent agenda in materials technology</td>
<td>• Literature reviews (LR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 2. Analysis of books on materials technology for ID and ED | • Materials books for ID & ED  
• Visual analysis tools for checking: (1) Types of Models; (2) Graphical Strategies; (3) Graphical Techniques; and (4) KEPs of VCT | | |
| 3. VTIs analysis, redesign and questionnaire survey | • Results/outcomes from books analysis above; and KEPs of VCT  
• VTIs from books and selected papers  
• Own design practice: VTIs  
• Survey questionnaire: checking KEPs applied and effectiveness of VTIs | 10 LDS ID Masters students  
12 METU ID Masters students  
19 PiS ED students  
6 LDS BSc students (ED) | Purposive & voluntary  
Purposive & voluntary  
Purposive & convenience  
Purposive & voluntary |
| 4. Validation: Experts discussions | • VTIs Questionnaire and introduction PowerPoint slide (used in the survey)  
• PowerPoint slide reports the triangulation findings (LR assertions and findings; books analysis results; and VTIs survey results)  
• Questions to ask the materials experts related to the results. | • Materials experts from: (1)LDS; (2)METU; (3)PiS | Purposive |

Table 3.4 Overview of Methods, Instruments and Samplings involved in this Research
Chapter 4 Redesigning Images Using KEPs of VCT

Chapter Overview

Chapter Four reveals the analyses and the redesigning processes for a number of existing visuals from different selected sources in the areas of kite and materials technologies. The analyses and the redesigning criteria are mainly based upon the established key emerging principles of the VCT. The redesigned visuals are used as tools in the case studies, which will be elaborated accordingly in the next three chapters. Figure 4.1 illustrates how Chapter Four fits into the structure of this thesis.
4.1 Visual Information of Kite Technology

A ‘poster’ – a form of visual information, was selected to display the kite-technology in this study. The study was a trial to apply key emerging principles (KEPs) in designing and redesigning of visual-technological-information (VTI).

Technological knowledge for kite-making relates to aspects of structures, materials and fluid dynamics. This information is widely and readily available in both printed and online resources. Thus, the content of the kite-poster design (a representation of the kite-technological-information in poster form) was mainly referenced and adapted from these three sources:

1. *KITEWORKS: Explorations in Kite Building and Flying* (Figure 4.2)
2. *KITES: The Science and the Wonder* (Figure 4.3)
3. *Key Stage 3 (for 11 – 14 year olds) Design and Technology Resource Pack* (Figure 4.4)
4.1.1 Visual-technological-information for kites

‘Making different shaped kites fly’, was one of the goals emphasised by Ito and Komura (1983), and they provided greater understanding of the technology behind the kite-making offering the potential for more creative outcomes. This became a key aspect of the kite’s VTIs designs. There were three formats of the kite-VTI designed and used in this study, but all of them exactly consist of the same kite-technological-information. The kite-technological-information is presented in three different formats; because they were most appropriate and suited the formats of the three surveys conducted and yet keeping the same represented information. The issue of the effect of the different formats was decided to be of lesser significance because the most important aspect of the study was measuring the connections of the technological information to designing and creativity. It was not about the detailed features of the design format.

The first set of kite-VTI was designed with the minimum of text and in two posters format for Case Study-1, conducted at Loughborough University (LU), UK. Poster-1 covers the basic structures of kites – implying any shaped kite can be made to fly (Figure 4.5). Poster-2 provides information about the performance of kites, explaining forces acting on the kite while flying; finding the centre of gravity for kite balancing; troubleshooting and solutions for kite flying and instability (Figure 4.6).

Figure 4.5
Any Shaped Kite Can Fly (Poster-1), Beh, 2009 (snake kite taken from Norman and Cubitt, 1999)

Figure 4.6
Kites: Performance and Troubleshooting (Poster-2), Beh, 2009 (illustrations taken from Norman and Cubitt, 1999)
The two posters were then modified to become one in an A4 size, so as to fit into half of the A3 format questionnaire (Figure 4.7) used for the comparative study conducted at Politeknik Ibrahim Sultan, Malaysia. The change was made to achieve a compact format, in order to be easier to administer for the overseas purpose; and the opportunity was taken to make it simpler in design form and complex in carrying information (applying the KEP-4, which will be further explained in section 4.2.2 in this chapter). Although the format changed to suit the later study, the content and messages remained essentially the same.

Figure 4.7
Kites: Performance and Troubleshooting in A3 Questionnaire Format (VTI used in Malaysia, modified to match the survey format; illustrations taken from Norman and Cubitt, 1999)
Figure 4.8 is the third redesigned version of the kite-VTI used in Case Study-2. It was redesigned to provide a fair comparison to the visuals selected from the 16\textsuperscript{th} Century (Figure 4.9) and with consideration of a better application of the KEPs. An overview of the information is provided on the left segment, whereas the details stories of the information are displayed on the right segment of the visual. The alteration was also meant to bring back the essence of the first set of the kite posters, and to fit in a PowerPoint slide presentation. This was the format that had been selected in order to setup the eye-tracking tests concerning the readers’ scanning patterns to verify the KEPs. Although the second set of kite-VTI used for the Malaysian study captured most of the original content and applied the KEP-4 (will be explained in section 4.2.2), the design had lost the spirit of ‘any shaped kite flies’. The results of Case Study-1 suggested that the visual information contained in the red smaller panel in Figure 4.8, which is small (compared to the first set of posters) but precise (compared to the first set posters and second kite-VTI), and which incorporated the previous original samples of kites, had played quite an important role in highlighting its key message.

The red panel on the left served as a point for calling attention, as it was in red colour, so the eye should be able to see it first; thus it had created the reading from left-to-right. The arrangement of 4 sections in red panel also served as a reading guidance for the reading intention in blue panel, which was to prepare the viewers to read from top-down direction. A common reading pattern of a passage would be from left-to-right and top-down, so the design intention would be reading from red panel to blue panel; and left-section, top-down to right-section, top-down sequence in blue panel (this reading pattern was also confirmed in the results of eye-tracking experiment on kite-poster, reported in section 6.4, Chapter 6).
Figure 4.8
Kites Visual-Technological-Information
(Beh, 2009; illustrations taken from Norman and Cubitt, 1999)

Figure 4.9
Exploded and Extended Drawing of a Ratchet Device, da Vinci 1500
(Leonardo’s ratchet device of c. 1500 is shown assembled (at left) and ‘exploded (at right) cited in Ferguson, 1993, p. 88)
4.1.2 Design and redesign of kites VTI

An essential aspect for the designs of kite-VTI was applying the KEPs of VCT established from the literature review, so as to test and confirm their validity. Other aspects of design such as graphical techniques highlighted by Tufte (1990; 2004; 2006) were also considered during the design and redesign processes. The elaborations of each characteristic of the KEPs can refer back to section 2.6 in Chapter Two. The KEPs are:

**KEP-1**: Facilitating COMPARISON to reveal CONNECTION and RELATIONSHIP

**KEP-2**: Unity of FORM to accentuate FUNCTION

**KEP-3**: PRECISION of data to communicate ACCURACY and inform the TRUTH (meaning, message, dimension etc.)

**KEP-4**: SIMPLE in design form; COMPLEX in carrying data or information

The overall ideas and concepts of the kite-poster design were as follows:

- **Poster layout**: The layout was set in a simple symmetrical format. This meant for easy visual scanning in terms of the following factors.

  1. Encouraging ‘comparison’, making ‘connections’ and ‘relationships’ within the information, e.g. the four basic types of kite structures were placed side-by-side and up-and-down in a quadrants-section format in Poster-1, enabling the viewer to distinguish four different structures of kites. The clearly defined quadrate sections were also dividing the scientific and technological information and their troubleshooting strategies, thus providing a useful visual guide for comparing and make connections in Poster-2. This was in compliance with the KEP-1 (‘facilitating comparison to reveal the connection and relationship’).
2. The format of this quadrants-section was also meant to provide visual guidance for a certain reading sequence in order to aid the viewers to read and hence comprehend the poster (like reading a passage in a page). A visual field that was created for reading or mapping direction would allow viewers to read from upper left to lower left (1-to-2), then from upper right to lower right (3-to-4); or it also could be read from top-to-down (1-3-to-2-4) in an overall instance, as illustrated in Figure 4.10.

![Figure 4.10 Format of the Kite-Poster Design](image)

A complete vertical line in the centre divided the plane into 2 sections (exactly like a 2 columns format page); and another 2 horizontal lines separately placed in the middle of 2 sections columns to create the quadrant. These 2 horizontal-lines did not cross all the way through the vertical line, intentionally leaving gaps before touching the line, to suggest that those were a section break of 2 paragraphs. Thus, the reading pattern had been controlled in a common pattern of reading a passage in a page, which was reading from the left section (from up-to-down), and then moving to the right section and reading from up-to-down again. This was compliant with the KEP-2, using a ‘form’ to accentuate the ‘function’ of reading visual information in an intentional pattern or particular format.
Thus, the kite-information that was placed in sections 1 and 2 (in Figure 4.10) was intentionally providing some clues (wind forces and kite-flying), but not quite explaining ‘how to do’. Instantaneously, these clues could encourage or create a need to search for further information in order to understand what the poster was about. That was why more information was just placed side-by-side on the right panel (sections 3 and 4 in Figure 4.10 to inform the centred technique of bridle-attachment and instability troubleshooting technique); deliberately to complement the whole story of the kite-making in the poster. This intention was only considered successful, if the complete comparison between the 2 panels and 4 sections had done and connections made, as well as having built up their relationships within the depicted visual elements by the viewers.

3. The symmetry was also meant to hint at the importance of balance in kite-structure, as a kite needs an overall stability in order to be lifted. This is particularly in compliance with KEP-2, where the symmetrical ‘form’ accentuates the requirements for the kite ‘function’.

4. The simple symmetrical form matches the KEP-4, which is ‘simple’ in design form, but ‘complex’ in carrying the technological information about the kites.

- **Annotated and diagrammatic illustrations**: The posters were designed with the very minimum of text and annotations. The diagrammatic illustrations were used to serve an essential role in informing about approximate angles, directions of forces acting and the centre of gravity of kites. This is in order to comply with the KEP-3 (‘precision’ of data to communicate ‘accuracy’ or inform the ‘truth’).
Other graphical techniques that were embedded in the kite-posters included those techniques emphasised by Tufte (1990; 2004; 2006):

1. Repeated sequences of visual elements (small multiples) (Tufte 1990) which help in guiding viewers to follow the information. This is similar to what had been done using the KEP-1 and KEP-2 as described in the previous section (1) under ‘Poster Layout’. The repeated visual form that had been arranged in four sections in the kite-VTI helped to carry the KEP-1 (to encourage the comparison, making connections and relationships), had worked as a sequence that guided the viewers to follow the information. Moreover, the repeated sequences of visual elements match the KEP-2 (i.e. they served as a ‘form’ that helps to accentuate the ‘function’ of guidance for informing).

2. Coherence of words, numbers and images (Tufte 2006, p. 119-121): good proportion and scales of line weight, lettering and shape of graphics. This is comparable to the annotated and diagrammatic illustrations in the kite-poster-2 that applied the KEP-3 (providing ‘precision’ of data to communicate ‘accuracy’ and inform the ‘truth’ of kite technology).

3. Provision of summaries of evidence about the specific characteristics of relationships (Tufte 1990). This is done via the visual arrangement of grouping visual elements into quadrate sections and grouping their detailed information in similar categories. For example, the red poster section (in Figure 4.8) served as one ‘chapter’ and the blue section as another ‘chapter’; sections divided by red or blue lines served as different sections in that particular chapter; and groups of illustrations or pictures (which are either different in sizes or different grouping panels) served as ‘paragraphs’ and ‘phrases’ in that section. In short, a summary of kite-technology and its relationship to getting any shaped kite to fly, troubleshooting for kite-flying and achieving stability are all being told in the depiction of the kite-VTI.
4. Layering and separation of data (Tufte 1990), which was applied in different hierarchical stages of information by providing different sizes and weight of lettering to titles, headings and subheadings; and the sizes of the illustrations and photos in the kite-VTI design (particularly obvious in the third version of redesign, Figure 4.8). These treatments made the information appear visually to have separated layers of information.

4.2 Visual Information of Materials Technology

Diagrams, illustrations and graphs (representations) are primarily the visual-technological-information (VTI) source used in most text books and scholarly papers; thus they were selected to represent the VTI for this study. The studied sources, from which the representations were selected, included:

1. Materials and Design: The art and science in materials selection in product design (Figure 4.11)
2. Materials Selection in Mechanical Design (Figure 4.12)
3. Five scholarly papers from Special Files of METU’s Journal of The Faculty of Architecture 2010, vol. 27, no. 2. (Figure 4.13)

![Figure 4.11 Materials and Design (Ashby and Johnson, 2004)](image1)

![Figure 4.12 Material Selection in Mechanical Design (Ashby, 2005)](image2)

![Figure 4.13 Journal of The Faculty of Architecture, vol.27, no. 2. (2010)](image3)
The selected representations were first analysed in terms of their strengths and weaknesses based upon the key aspects of the KEPs established. Then, redesigned versions were developed to strengthen the weaker aspects that had been identified. These predominantly involved the forms, layouts and detailed visual elements and/or annotations applied in those representations. Tables 4.1 until 4.14, in the following sections, reveal the analyses of the existing visual representations, and illustrate the considerations and criteria used in the redesign processes that have been carried out. The analyses and redesigns are explained and described in the following manner:

4.2.1 Analysis (Table 4.1) and redesign (Table 4.2) of ‘life cycle of a material’

4.2.2 Analysis (Table 4.3) and redesign (Table 4.4) of ‘design process’

4.2.3 Analysis (Table 4.5) and redesign (Table 4.6) of ‘meaning of materials model’

4.2.4 Analysis (Table 4.7) and redesign (Table 4.8) of ‘connotation of product aesthetics’

4.2.5 Analysis (Table 4.9) and redesign (Table 4.10) of ‘matrix for developing the chromatic atlas of materials for design’

4.2.6 Analysis (Table 4.11) and redesign (Table 4.12) of ‘material languages’

4.2.7 Analysis (Table 4.13) and redesign (Table 4.14) of ‘material selection activities and information sources’
4.2.1 Analysis and redesign of the representation of ‘Life Cycle of a Material’

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1</strong> [COMPARE &gt; RELATIONSHIP] The overall structure clearly helps to signify a cyclic relationship of a product – a car and its production in this case.</td>
<td></td>
</tr>
<tr>
<td><strong>KEP-2</strong> [FORM &gt; FUNCTION] Some physical forms of the elements are easy to identify, and the overall form accentuates the function of a cycle.</td>
<td><strong>KEP-2</strong> [FORM &gt; FUNCTION] Some forms of the elements are not as easy as others to instantly identify what they are representing instantly.</td>
</tr>
<tr>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH] The form and layout suggest some ideas of precise and true information.</td>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH] The truth of information is presented, but not in a very precise way or in great detail, because some of the elements need some guessing to establish their intended meaning or depicted characteristics.</td>
</tr>
<tr>
<td><strong>KEP-4</strong> [SIMPLE design &gt; COMPLEX data] Yes, it has a very simple design form, and it also carries much more information than it might seem initially.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1
Analysis of the Life Cycle of a Material (image cited in Ashby and Johnson 2004, p. 11)
Chapter 4 Redesigning Images Using KEPs of VCT

Redesign Criteria and Strengths

**KEP-1 [COMPARE > RELATIONSHIP]**
The whole previous structure is kept with slight improvement in terms of the KEP-2 (form) and -3 (accuracy), so as to make the relationships depicted become clearly visible and unambiguous for comparing and making connections.

**KEP-2 [FORM > FUNCTION]**
Frames, title and captions are integrated into the forms of individual elements for clarity of their individual characteristics, so as to eliminate any possible ambiguity.

**KEP-3 [PRECISE > ACCURACY/TRUTH]**
Title and captions help to provide precise details, especially informing the intended meaning clearly and immediately, thus readability is increased.

**KEP-4 [SIMPLE design > COMPLEX data]**
Simple design form that carries complex information is retained.

Table 4.2
Redesign of the Life Cycle of a Material
(Beh, 2011; adapted from Ashby and Johnson 2004, p. 11)
4.2.2 **Analysis and redesign of the representation of ‘Design Process’**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
</tr>
<tr>
<td>Each detail in this structure seems to have some guides that link them to the central feature (design process), therefore signifying their connection and the relationships among them.</td>
<td>The links and relationships can only be read by very careful observation. This is due to the failure to observe KEP-2.</td>
</tr>
<tr>
<td><strong>KEP-2 [FORM &gt; FUNCTION]</strong></td>
<td><strong>KEP-2 [FORM &gt; FUNCTION]</strong></td>
</tr>
<tr>
<td>A stimulating overall form starts to highlight the 6 aspects in relation to the central process (function of the form starts to work).</td>
<td>It is quite difficult to see which sectors belong to the causes, and which to the effects. The detailed forms or supporting guides (the arrows) are depicted too subtly to accentuate their function as guiding direction; therefore the relationships are hardly seen in an instantaneous manner.</td>
</tr>
<tr>
<td><strong>KEP-3 [PRECISE &gt; ACCURACY/TRUTH]</strong></td>
<td></td>
</tr>
<tr>
<td>KEP-1 and -2 suggest some good guidelines to inform precise and true information in subtle integration.</td>
<td></td>
</tr>
<tr>
<td><strong>KEP-4 [SIMPLE design &gt; COMPLEX data]</strong></td>
<td></td>
</tr>
<tr>
<td>Yes, it has a simple design form and carries complex information about the design process.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3
Analysis of Inputs of the Design Process (image cited in Ashby and Johnson 2004, p. 8)
KEP-1 [COMPARE > RELATIONSHIP]
The format of its previous structure is kept with KEP-2 improved to make the relationships clearly visible, so that it becomes easy to compare the information and make connections.

KEP-2 [FORM > FUNCTION]
An overall form that emphasizes 6 aspects of causes and effects is kept. Representational forms of arrows (triangles) and the arrow itself are increased in sizes; colours and tonality are also added to the arrows, emphasizing the directionality (as to whether it is a cause or an effect; also to depict hierarchy of information and specifications), and these depictions become visible and clear. Placement of text with the support of arrows enhanced the meaning of cycling or continuous process of design. The inwards-pointing-arrows clearly and instantaneously accentuate the influential factors that affect the process; while the outwards-pointing-arrows as to the concerning outcome causes with regards to the designing process.

KEP-3 [PRECISE > ACCURACY/TRUTH]
KEP-1 and -2 have been improved therefore precise links of information from one level to another are clearly visible and readable, thus true stories of the design process are depicted.

KEP-4 [SIMPLE design > COMPLEX data]
Simple design form that carries complex information is retained.
### Analysis and redesign of the model of ‘Meaning of Materials’

#### Table 4.5

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
</tr>
<tr>
<td>Three components in the representation: User, Material and Product are clearly visible with slight hints of their relationships within the context.</td>
<td>The depiction of relationships (the connections within the 3 components) needs very careful observation in order to be comprehended about the messages carried and their links within the context. This is due to failure to observe the 2 main functions in KEP-2.</td>
</tr>
<tr>
<td><strong>KEP-2 [FORM &gt; FUNCTION]</strong></td>
<td><strong>KEP-2 [FORM &gt; FUNCTION]</strong></td>
</tr>
</tbody>
</table>
| The structure or the placement of the 3 main forms suggests some connections within the context. | 1) Individual forms do not encourage the readers to link to the meaning/characteristics they carried; and the placement can be ambiguous. eg: the user, material and product are represented in very abstract ways; and the ‘context’ line seems like it must start from the ‘technical properties’ and gradually travel in a spiral motion to reaches the outer link of components like product brand, function etc.  
2) Depictions of the connectivity are too subtle to be seen immediately, as they lack an immediate readable quality as a diagram. |
| **KEP-3 [PRECISE > ACCURACY/TRUTH]** | **KEP-3 [PRECISE > ACCURACY/TRUTH]** |
| The visual information provides precise details. | The truth is slightly ambiguous, as details mentioned in KEP-2. |
| **KEP-4 [SIMPLE design > COMPLEX data]** | |
| Yes, it is simple in design form and carries complex information about the meaning of materials. | |

*Table 4.5 Analysis of the Meaning of Materials Model (image cited in Karana 2010, p. 276)*
**KEP-1** [COMPARE > RELATIONSHIP]
The format of the previous structure is kept with KEP-2 and -3 modified to make the relationships clearly visible in order to allow the readers to compare and understand their connections.

**KEP-2** [FORM > FUNCTION]
Representational forms and planes for user, product and context are used to replace the abstract circles and spiral lines, accentuating the individual elements for clarity of their concerning characteristics and meanings; arrows are modified to increase directionality guidance of the links of relationships, so as to increase instant readability.

**KEP-3** [PRECISE > ACCURACY/TRUTH]
Precise details are listed one after the other with clear guidelines to represent their meaning in relation to other elements, thus showing the truth of visual depiction as well as the story behind it.

**KEP-4** [SIMPLE design > COMPLEX data]
Simple design form that carries complex information is retained.

---

Table 4.6
Redesign of the Meaning of Materials Model
(Beh, Norman and Yap, 2011; adapted from Karana 2010, p. 276)
### 4.2.4 Analysis and redesign of the depiction of ‘Connotation of Product Aesthetics’

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1</strong> [COMPARE &gt; RELATIONSHIP]</td>
<td>The structure creates ambiguity in terms of expressing the relationships among the aesthetics: 1) It can be interpreted as ‘cultural aesthetic’ is the heart or core of all other aesthetics; or 2) cultural, psychological, functional and technical aesthetics are under a bigger concept of ‘sensory aesthetic’.</td>
</tr>
<tr>
<td><strong>KEP-2</strong> [FORM &gt; FUNCTION]</td>
<td>The circular forms (rings) create ambiguity: 1) Being in the centre and in dark gray suggests that ‘cultural aesthetics’ is the most important as it was like a ‘target’; or 2) Rings are embracing one after another, suggesting that the largest ring is the major family of other smaller inner rings, projecting the meaning that all other aesthetics are under the major one. These issues caused the problems in the KEP-1 (above).</td>
</tr>
<tr>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH]</td>
<td>Precise information is given.</td>
</tr>
<tr>
<td><strong>KEP-4</strong> [SIMPLE design &gt; COMPLEX data]</td>
<td>Although the design form is pleasant and simple, and it carries much information; it fails to carry a straightforward message without any ambiguity.</td>
</tr>
<tr>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH]</td>
<td>Although it provides a great deal of information or examples of each aesthetic, the presentation of the precise details are misleading, and thus the data is no longer true or accurate.</td>
</tr>
</tbody>
</table>
**KEP-1 [COMPARE > RELATIONSHIP]**
The format is totally reconstructed (as described in KEP-2 below) in order to highlight the connections and relationships among the 5 equally important and compatible perspectives of the product aesthetics.

**KEP-2 [FORM > FUNCTION]**
A pentagon formed by 5 triangles is the key to the structure and enhances the key message. Each triangle clearly states its subtitle and carries its own characteristic. The 5-triangle form produces obvious visual guidance pointing inwards to the key words – ‘product aesthetics’, instantly displays the connectivity and relationships of the 5 aspects within the spectrum of product aesthetics. Thus, the unity of form has successfully functioned as message-provider, as well as increased the readability of the representation.

**KEP-3 [PRECISE > ACCURACY/TRUTH]**
Description of details or examples of individual aesthetic characteristics are organised and well fitted in each form of triangles. This is not only showing precise organisation, but also presents true/accurate information with clear readability.

**KEP-4 [SIMPLE design > COMPLEX data]**
Simple in design form and carries complex information is retained.
4.2.5 **Analysis and redesign of the ‘Matrix for Developing the Chromatic Atlas of Materials for Design’**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1</strong> [COMPARE &gt; RELATIONSHIP]</td>
<td>The relationships depicted seem not as they were described in the text. According to the text, the colour axis should be swapped with the material axis. The technology axis seems ambiguous in a 3-axes graph relationship.</td>
</tr>
<tr>
<td><strong>KEP-2</strong> [FORM &gt; FUNCTION]</td>
<td>The 3-axes graph does not fully function as it should by showing the correspondence relationships. The technology-axis is only shown as another dimension of the information, which does not provide any direct correspondence to the other 2 axes. Example, the vertical planes that project into a 3D space, showing only links between material- and colour-axes, it does not relate to any of the listed information on the technology-axis. Thus, it is not communicating the relationships well.</td>
</tr>
<tr>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH]</td>
<td>Almost precise information is given.</td>
</tr>
<tr>
<td></td>
<td><strong>KEP-3</strong> [PRECISE &gt; ACCURACY/TRUTH]</td>
</tr>
<tr>
<td><strong>KEP-4</strong> [SIMPLE design &gt; COMPLEX data]</td>
<td>Simple design form with complex data.</td>
</tr>
<tr>
<td></td>
<td><strong>KEP-4</strong> [SIMPLE design &gt; COMPLEX data]</td>
</tr>
</tbody>
</table>

Table 4.9
Analysis of Matrix for Developing the Chromatic Atlas of Materials for Design
(image cited in Rognoli 2010, p. 295)
KEP-1 [COMPARE > RELATIONSHIP]
A similar goal is kept for the structure: 3-axes that represent 3 components. The visual depiction is clearly showing the corresponding relationships played by each component in a 2D table (for 2 axes) and a 3D visual representation (the 3rd axis).

KEP-2 [FORM > FUNCTION]
1) The coloured planes are placed in an in-depth position with dashed arrow to inform that there are more of these coloured charts/cards. The additional grey arrows, which are pointing to the same “colour” axis, indicating that there are other colour formats included in that chart.

2) The 2-axes table correspond between the “material” and its “technology” involves in producing the colour presented by the card. The forms (both the 2D table and the colour planes) are well accentuating their function in depicting their interrelated relationships.

KEP-3 [PRECISE > ACCURACY/TRUTH]
Precise details are organised in 3 corresponding axes, thus the visual is able to present its true/accurate information.

KEP-4 [SIMPLE design > COMPLEX data]
A complex and ambiguous design form is modified into 2 simple layers (1 is a common 2D table; and the other is multiple cards placed in 3D space); and the overall structure carries a complex data of materials, colours and the technologies to produce the colours.

Table 4.10
Redesign of Matrix for Developing the Chromatic Atlas of Materials for Design
Beh & Norman (2011)
### 4.2.6 Analysis and redesign of the representation of ‘Material Languages’

#### Strengths

<table>
<thead>
<tr>
<th>KEP-1</th>
<th>[COMPARE &gt; RELATIONSHIP]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall structure encourages the comparison of individual and segments of information, therefore the relationships between most of the elements are visible and readable.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-2</th>
<th>[FORM &gt; FUNCTION]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) The Representational forms (both non-technical icons and technical numerical symbols) are well depicted in their characteristics and meanings.</td>
<td></td>
</tr>
<tr>
<td>2) Arrows provide clear directions for either technical or expressive judgements.</td>
<td></td>
</tr>
<tr>
<td>3) The circular forms (rings) suggest the unity of one form.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-3</th>
<th>[PRECISE &gt; ACCURACY/TRUTH]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise information and almost true stories are depicted.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-4</th>
<th>[SIMPLE design &gt; COMPLEX data]</th>
</tr>
</thead>
<tbody>
<tr>
<td>It embraces simple qualities of form and carries much information.</td>
<td></td>
</tr>
</tbody>
</table>

#### Weaknesses

<table>
<thead>
<tr>
<th>KEP-1</th>
<th>[COMPARE &gt; RELATIONSHIP]</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is difficult to make connection and read the relationships between the visual elements depicted in the central rings to the rest of the information.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-2</th>
<th>[FORM &gt; FUNCTION]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The representational forms in the central rings are slightly ambiguous in depicting their meanings; they could mean materials of any product or the products themselves. Thus, their links to other components of information are indirectly affected, so that the overall meaning could be interpreted as material or product, divided into two types of information, between information embedded in a material and information encoded about a material. Thus, accuracy of information becomes questionable.</td>
<td></td>
</tr>
</tbody>
</table>

---

**Table 4.11**

Analysis of Material Languages (image cited in Pedgley 2010, p. 347)
Redesign Criteria and Strengths

**KEP-1 [COMPARE > RELATIONSHIP]**
The whole previous form-structure is kept with slight changes in terms of the KEP-2 (form), so as to make the relationships depicted become more obvious and unambiguous for comparing and making connection.

**KEP-2 [FORM > FUNCTION]**
1) The representational forms in the central ring are replaced by experiments of a product, depicting the meanings of its material being tested by a device and also by hand (sense of experiencing). Thus, the overall depiction has projected the meaning of obtaining two types of information via two ways of judgements. It is definitely not presenting the material or product as divided into two types of information.

2) The rings suggest the unity of one form, depicting one issue seen in two perspectives and therefore providing two types of information.

3) The dashed lines no longer suggest a definite division line, instead it hints for two spaces for two perspectives within the rings that depicts two experiments and their technical and non-technical information. This is because the visuals in the central ring (as described above) help to change the meanings of the overall depiction.

**KEP-3 [PRECISE > ACCURACY/TRUTH]**
Precise information and a more accurate story of the embedded and encoded information or the technical or sensorial properties for a material are depicted. Material itself has "innate properties" as described by the author, but with different judgements, different information would be obtained; it is not that the material is divided into two information or two properties.

**KEP-4 [SIMPLE design > COMPLEX data]**
Simple design form and complex information are retained.

Table 4.12
Redesign of Material Languages
(Beh, Norman and Yap, 2011; adapted from Pedgley 2010, p. 347)
4.2.7 **Analysis and redesign of the diagram of ‘Material Selection Activities and Information Sources’**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
<td><strong>KEP-1 [COMPARE &gt; RELATIONSHIP]</strong></td>
</tr>
<tr>
<td>Segments of information seem to have connections and inter-related relationships.</td>
<td>The connections and relationships within the segments of information are subtly depicted; thus it needed some time to be clearly seen or read.</td>
</tr>
</tbody>
</table>

*Table 4.13 continues on next page...*
### Strengths

<table>
<thead>
<tr>
<th>KEP-2 [FORM &gt; FUNCTION]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ellipse forms start to hint at the links within the segments of information. The human figures suggest some sort of representational characters, and are connected to the segments of information.</td>
</tr>
</tbody>
</table>

### Weaknesses

<table>
<thead>
<tr>
<th>KEP-2 [FORM &gt; FUNCTION]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The elliptical links provide subtle guidance of directionality, making the readers need extra careful or close inspections to see the looping links. Extra arrows in a single loop increases ambiguity and complexity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-3 [PRECISE &gt; ACCURACY/TRUTH]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise information and almost true stories are presented.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-4 [SIMPLE design &gt; COMPLEX data]</th>
</tr>
</thead>
<tbody>
<tr>
<td>It has some simple qualities in certain parts of the diagram and carries much information.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEP-4 [SIMPLE design &gt; COMPLEX data]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Although the diagram seems simple and quite pleasant, the information is presented via 2 diagrams, making it seems to have repeated information.</td>
</tr>
</tbody>
</table>

Table 4.13

Analysis of Material Selection Activities Model and Information Sources (image cited in van Kesteren 2010, p. 326)
KEP-1 [COMPARE > RELATIONSHIP]
Categorising information by presenting them in similar visual treatments, and in hierarchical organisation improved the smoothness of comparing the connections within each segment and level of information, as well as making the relationships become visibly clear.

KEP-2 [FORM > FUNCTION]
1) Simple and direct forms of arrows are employed to make the links and guides for directions visible in a glance. Arrows for a single loop are reduced to a minimum, and have been presented in a hierarchical manner in order to decrease the possible ambiguity and complexity.

Table 4.14 continues on next page...
4.3 Reliability and Validity for the Study

The design-and-redesign images using the KEPs study was considered reliable and valid based on the following rationale:

- The study was reliable as the processes leading to the outcomes were completed via a triangulation. It began from literature survey and established the KEPs of VCT. The second practice was developing the visuals (either was a new design or a redesign), which were used as the VTIs, by applying the established KEPs. The triangulation was completed by testing the VTIs in the series of case studies.

- The validity of the design-and-redesign study was gained through another round of action for confirmation, e.g. another case study, eye-tracking with scientific device, or experts’ focus group, depending on each relevant case.

**Redesign Criteria and Strengths**

**KEP-2 [FORM > FUNCTION]**

2) Individual human representation is replaced by a set of general man-and-woman figure and a list of words, simple and straightforward to describe those personnel involved. Colour is introduced to differentiate the categories of information in the same diagram. Thus, all sorts of ambiguities and the act of having to keep checking the legend of human figure representation are all eliminated.

3) An almost symmetrical structure and the merging of several styles and 2-diagrams into one structure are applied to help the readability become smoother.

**KEP-4 [SIMPLE design > COMPLEX data]**

The complex information is depicted hierarchically in a one structure format and in one diagram (meaning the structure/form of the diagram is simplified). Overall, it still carries complex stories with precise details.

Table 4.14

Redesign of Material Selection Activities Model and Information Sources
(Beh and Yap, 2011; adapted from van Kesteren 2010, p. 326)
Chapter 5  Case Study-1

[VCT > Designing > Creativity/Innovation]

Chapter Overview

Chapter Five describes the first case study carried out in this research, which was designed to gather empirical evidence of the links between the VCT, designing, creativity and innovation. The design of the case study, its data collection methodology and results are reported in this chapter. Figure 5.1 illustrates how Chapter Five fits into the structure of this thesis.
5.1 Case Study-1 Design

The intention of this study was to seek evidence of links because most people claim that visual communication facilitate manipulation in the mind, and hence inculcates creative and innovative values for supporting designing more effectively. To trace these links, a miniature-kite-designing task was designed to enable empirical data concerning VCT, designing, creativity and innovation to be gathered in a manageable timeframe within the case study. The design of the case study has taken into consideration the appropriate aspects of technological knowledge, the capability to track the links and measure creativity, and finally time and cultural issues.

5.1.1 Technological knowledge for kite design

Kite-making involves several technologies such as aspects of structural design, materials and the mechanics of kite flying. These aspects, reported by Ito and Komura (1983), involve a wide range of scientific fields, e.g. fluid dynamics, analytical mechanics, material properties and strength analysis, and meteorology. Thus, selected information from these technologies is what is needed by designers in order to make a kite that flies.

5.1.2 Tracking the complex chain of VCT > Designing > Creativity/Innovation

The kite-designing-task provides a rich context. It enables tracking and the intended assessment of the complex chain, starting from accessing the kite-posters (a kite-visual-technological-information or in short kite-VTI) as to whether it supports designing, and facilitating creativity and innovation. According to Ito and Komura (1983, p. 12), after four years of experimenting and proving the science of kites, they emphasise that “In order to be creative, it is essential to know how things work. The more the range of creation extends, the more it is necessary to understand most basic tenants.” There is also a value-driven orthodoxy concerning kite-design which leads to previously successful shapes being replicated unnecessarily.
Thus, there is the potential for greater understanding of the technology behind the kite-making leading to more creative outcomes. This distinction between replication and novel forms provides the opportunity for an appropriate empirical measure of creativity.

5.1.3 Measuring the creativity and innovation

The creativity embodied in the students’ kite-design-outcome was evaluated by drawing upon Thistlewood’s (1990) analysis of historicist and archetypal categories of designing; and Spendlove’s (2005) review of creativity in education. The creative design level of archetypes can be associated with little ‘c’ creativity; and the historicist level can be related to big ‘C’ creativity (an approach used by Gardner, 1993; Simonton, 2000; and Craft, 2001 for the classification of creativity), as stated by Spendlove (2005).

‘Artefacts’ are products which have developed through the generations and where “significant departure from these characteristics leads at best to less-fit artefacts and at worst … to retrograde mutations” (Thistlewood 1990, pp. 14-15). Spendlove (2005, p. 11) specifies that little ‘c’ creativity is often used to indicate the ability of students to manage incremental change, problem-solving and the ability to adapt to change on a daily basis. Little ‘c’ creativity is likely to be a characteristic of designing artefactual products, or products that the designer regards as artefactual. Changes are likely to be restricted to altering factors such as of colour, texture or the material, but the essential form will be retained.

Thistlewood (1990) refers to two categories of designing where the form is change. ‘Historicist’ designing is where new examples do not supersede their predecessors because there is no essential form (Thistlewood 1990, pp. 14-15). ‘Evolutionary’ designing (Thistlewood 1990, pp. 15-16) obliges the designer to invent new forms that invalidate all their predecessors; e.g electronic typesetting has invalidated hot metal.
The latter concept is related to big ‘C’ creativity, which according to Spendlove (2005, p. 11) happens when a creative solution to a problem establishes a ‘high novel’ response that shifts how other people think and live their lives.

These two characteristics, retaining an exciting form and changing that form provide a framework for an objective assessment of the creativity embodied in the kite designs.

The creativity assessment criteria that were adopted and applied in judging the students’ kites were the following:

1. Those kites that were not copying the existing kites made available to the students, common kites available in the market or those had been displayed in the museums were judged to be ‘Historicist’ designing with big ‘C’ creativity.

2. Those kites where the structure and shape seemed inherited from those of existing kites, but with slight changes in details would be considered as ‘archetypal’ designing with little ‘c’ creativity.

3. The ultimate judgement of creativity and innovation (if there is any) would be of totally new forms or structures of kites, which would be regarded as representing ‘evolutionary’ designing.

5.1.4 Time issue

The process of kite-designing and -making, particularly in small scale (miniature) can be completed within 30 minutes to an hour. After the outcomes of kite-design were recorded, the assessment of creativity and innovation could also be conducted immediately. Thus, the task was considered to provide a manageable timeframe to obtain results for further analysis.
5.1.5 **Cultural differences**

Kite-flying is universally popular around the world and for many purposes. Kites are well-known as either children’s toys, or objects in game; or in some parts of the world, they serve important roles in religious ceremonies, incantations and local festivals (Ito and Komura 1983, p. 5/Preface). Kite-making has made its appearance in schools as a fun and creative activity, essentially a learning process; and to Ito and Komura (1983, p. 8/Preface), the kite can be an experimental tool for gathering some theories of sciences or engineering, based on its ease of production at low cost, and the aspects of technological and scientific behind the making. Since kite-making itself is a familiar language in learning without cultural barriers, it is also a potentially effective vehicle for investigating whether different cultures require different visual-technological-information (VTI); and whether key emerging principles (KEPs) of VCT have any barriers relating to cultural differences.
5.2 Data Collection Methodology

The kite-designing case study had six planned phases as shown in Figure 5.2.

**PHASE-1: Posters Design applying KEPs of VCT**

1.1(a) 1.1(b) 1.2
Posters 1.1(a) & (b) are used in UK study; Poster 1.2 is used in Malaysian study.

**PHASE-2: Access Information and Kite-Designing-Task in UK Study**

(145 freshmen of ID on The Induction Day of LDS, LU)

Information provided:
1. Actual Kites
2. Materials for kite-making
3. Kite-information-posters
4. Internet links of kite-information.

**PHASE-3: Evaluation of Creativity/Innovation**

3.1 Historicist (big ‘C’) vs Artefacts (little ‘c’)
3.2 Paired-Comparison of Perception

**PHASE-4: Questionnaire Survey**

Preferred Information Sources:
- Sources of inspiration
- Troubleshooting for structures, flying & instability
- Functional value in creativity

**PHASE-5: Comparative Study in Malaysia**

(24 ID; 24 ED Students)

**PHASE-6: Validation** (30 PGCE Trainees)
5.2.1 **PHASE-1: Posters design applying the KEPs of VCT**

Technological information about kites was displayed visually with a minimum of text by applying KEPs of VCT established from literature in the design of two posters for the UK study (explained in Chapter 4). Poster-1 depicted how any shaped kite can be made to fly (Figure 4.5). Poster-2 provided information about the performance and troubleshooting of kites (Figure 4.6). A similar concept of poster, but in a modified A4 size and developed by combining two posters into one, in order to become part of the questionnaire (Figure 4.7) was used in Malaysia for the comparative study.

5.2.2 **PHASE-2: Accessing information and kite-designing-task in the UK study**

A total of 145 ID students in year-1 study were provided with four sources of information about kites:

1. Actual kites
2. Materials for kite-making
3. Kite-information-posters
4. Internet links for miniature kite-making and flying techniques

The students were given one hour (after briefing) to have lunch together with accessing the internet information. The rest of the information was available all the time after briefing and during the one hour group designing and modelling session. Students designed and modelled their miniature-kites in groups of five for the UK group (part of the activities for Loughborough Design School (LDS) 2009 Induction Day, Figure 5.3). Design brief for this kite-designing task was in Appendix 5.1.
After completing the kite-making, each group explored test-flying their kites indoors using the wooden rods provided, as shown in Figure 5.5. All students’ groups are self-selected.

### 5.2.3 PHASE-3: Evaluation of creativity

Creativity in students’ kites was evaluated based on archetypal (little ‘c’) and historicist (big ‘C’) categories of analysis, examples are as shown in Table 5.1. See section 5.2.3 for a description of creativity assessment criteria (a complete evaluation and analysis can be found in Appendix 5.2).

<table>
<thead>
<tr>
<th>Existing Samples</th>
<th>STUDENTS’ KITE DESIGNS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Creativity Levels)</td>
</tr>
<tr>
<td></td>
<td>Identical</td>
</tr>
<tr>
<td></td>
<td>little ‘c’ (Archetypes)</td>
</tr>
<tr>
<td></td>
<td>big ‘C’ (Historicist)</td>
</tr>
<tr>
<td>none</td>
<td></td>
</tr>
<tr>
<td>none</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1

Sample of Creativity Analysis of Kites, based on archetypal and historicist categories of designing (Thistlewood, 1990) & (Spendlove, 2005). A complete analysis is shown in Appendix 5.2.
A paired-comparison method (Figure 5.4 and Table 5.2) was also used for the evaluation among the students. It was intended to explore the students’ perceptions of creativity and to validate the evaluation of creativity of the kites’ static forms. Kites’ performances (flying capabilities) were also put into paired-comparisons to explore whether functional aspects altered the perceptions of creativity. The comparison was conducted through viewing of recorded video clips (Figure 5.5). It was only possible to compare the final six kites (Kite-A to Kite-F in Table 5.3) from the static results due to time restrictions.

Students responded with their perceptions using the voting slip (Table 5.4) while viewing the paired photographs and video clips.
Kites Design in Block B

<table>
<thead>
<tr>
<th>BLOCK B</th>
<th>Comparison of Kites</th>
<th>Final List</th>
<th>Preferred Kite</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Kites 1, 2, 3, 4, 5</td>
<td>Kite-A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Kites 6, 7, 8, 9, 10</td>
<td>Kite-B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Kites 11, 12, 13, 14, 15</td>
<td>Kite-C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Kites 11, 12, 13, 14, 15</td>
<td>Kite-D</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Kites 11, 12, 13, 14, 15</td>
<td>Kite-E</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Kites 11, 12, 13, 14, 15</td>
<td>Kite-F</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.3
Methodology of Paired-Comparison

Table 5.2
Paired Comparison Results for Block B
(numbers indicate the decimal fraction of students preferring the kite in this column to the kite in the row)

<table>
<thead>
<tr>
<th>RANK</th>
<th>TOTAL</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd</td>
<td>2.41</td>
<td>0.50</td>
<td>0.52</td>
<td>0.23</td>
<td>0.89</td>
<td>0.45</td>
</tr>
<tr>
<td>2nd</td>
<td>2.67</td>
<td>0.48</td>
<td>0.52</td>
<td>0.28</td>
<td>0.75</td>
<td>0.31</td>
</tr>
<tr>
<td>4th</td>
<td>2.28</td>
<td>0.77</td>
<td>0.72</td>
<td>0.50</td>
<td>0.92</td>
<td>0.66</td>
</tr>
<tr>
<td>1st</td>
<td>3.14</td>
<td>0.11</td>
<td>0.25</td>
<td>0.92</td>
<td>0.50</td>
<td>0.08</td>
</tr>
<tr>
<td>5th</td>
<td>2.00</td>
<td>0.55</td>
<td>0.69</td>
<td>0.34</td>
<td>0.08</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The Winner

Table 5.4
Paired-Comparison Voting Slip
5.2.4 **PHASE-4: Questionnaire survey**

The questionnaires were designed in three stages. Firstly a set of questionnaires was used during the case study in the UK in order to find out students’ preferences of information sources. A second set of questionnaires was used for a follow up survey after the first results had been obtained. This set of questionnaires was about revisiting preferred sources of information if there was to be another chance for kite-making, and it was also to seek students’ views concerning their creative responses by comparing the results of kite-still-images and kite-performances. The third set of questionnaires was used during the validation study, which was developed only to look for specific messages that students perceived from the kite-posters. These questionnaires were developed based on the following foci.

**Stage-1 Questionnaire:**

Q1. Which sources of information have inspired the students the most for their kite design?

Q2. Whether the students have faced difficulties getting the kite to fly? If yes, what sources of information helped them to overcome the problems?

Q3. If the students did the project again with more time, which resources of information would they revisit, and when?

Q4. Did the students find the posters information about kites helpful? If yes, how so?

**Stage-2 Questionnaire:**

Q1. Many of the students wanted to look at the Internet more carefully if they repeated the project. What would they be looking for?

Q2. Do the students feel that the evaluated kites’ results accurately reflected the creativity of the design responses?

Q3. Do the students think that the showing of the kites’ videos would have changed the first set of ‘static’ results?
Stage-3 Questionnaire:

Q1. What is the students understanding of the key messages from the posters?

Questionnaires were given to the students and interviews were conducted with video recording for the data gathering and later analyses purposes.

5.2.5 PHASE-5: Comparative study in Malaysia

The comparative Malaysian groups were 24 ID students; and 24 ED students with the information provided:

1. Kite-information-poster
2. Internet links for kites

All the procedures including the accessing of information, the kite-designing task and creativity evaluations were almost the same as the study conducted in UK. However, the sources of information were reduced down to two (as shown above); and the self-selected groups of students were in groups of two for the ID and groups of four for the ED students in the Malaysian study (Figures 5.6 and 5.7). Design brief for this kite-designing task was in Appendix 5.3.

The change in information sources was based on the questionnaires results (from the Phase-4 of the study), which had found that they were the more significant and had most impact on the students’ designing task. The changes in the numbers in the student groups were due to the number of students available at that time in those particular classes.

Figure 5.6  Understanding Kites Poster & Listing the Key Messages, Malaysian ID group, 2010

Figure 5.7  Kite Designing Exercise, Malaysian ED group, 2010
5.2.6 **PHASE-6: Validation study in the UK (tracking the links between VCT > Designing > Creativity/Innovation)**

Thirty (30) trainees of Loughborough’s Post Graduate Certificate in Education (PGCE) programme were provided with Kite-posters (Figures 4.5 and 4.6) during their workshop: ‘Modelling > Designing > Graphicacy’ (MDG). The information sources, at this validation study, were reduced to only one source: the kite-posters. This decision was made based on the results of the Phase-4 (questionnaire survey) findings.

In groups of two (self-selected; Figure 5.8), the participants were asked to design and model their miniature-kites within one hour, followed by test-flying the kites indoors with the wooden rods provided (Figure 5.9). They were also given another 10 minutes to list down their understanding of the key messages from the posters in the provided questionnaire (Table 5.13). Before ending the session, a discussion was carried out mainly about the posters and linked to modelling, designing and graphicacy.

The creativity evaluation was again conducted using analysis based on archetypal and historicist, just as those conducted in the triangulation in this case study. A complete evaluation can be referred to Appendix 5.2.

---

**Figure 5.8**
PGCE Trainees study the kite-posters and design the miniature-kite in the MDG Workshop (2009)

**Figure 5.9**
PGCE Trainees test-flying the modelled miniature-kite in MDG Workshop (2009)
5.2.7 Sampling

The students who in the kite-designing (for all the three studies: two in the UK and one in Malaysia) were a purposive sample in that they represent students in particular categories, which were industrial design and engineering design. They were also from the two countries which have been selected for comparative study, i.e. the UK, where the research is being primarily conducted and Malaysia, who are sponsoring the research and where the outcomes will to be directly implemented. They could also be described as a convenience sample as they are a captive audience of students.

5.2.8 Piloting, issues and changes for Case Study-1

The first kite-designing task conducted in UK (on LDS 2009 Induction Day) was initiated as a pilot study, and the main case studies were to be refined thereafter. However, when the whole pilot exercise worked and provided promising results, particularly enabling the demonstration of the association of VCT with supporting designing, and also generated evidence of creativity, it was decided that the pilot case study could become part of the data for the actual Case Study-1. There were four sources of information in the pilot exercise. However, only two (kite-information-poster and internet-kite-information) were frequently referred to and preferred sources (result obtained from the pilot). Therefore, it was decided to only utilise these two sources for the comparative study in Malaysia.

A follow-up case (Validation Study in UK), therefore, seemed more appropriate and useful to establish in order to verify the initial findings. The validation case study was also conducted using a more direct approach to tracking links between VCT, designing and creativity. This involved a direct use of the kite-posters (which represent the VCT) as the only source, and hence the study was without distractions from other sources of information.
A questionnaire, which required participants to list down their understanding of messages from the posters, was also used as an aspect of the validation study with the PGCE trainees. This was intended to directly examine how the posters helped and was used for ideas development, design inspirations and solutions for kite-flying among the participants.

As a result of the above decisions, all the results (from the pilot case study, comparative study in Malaysia and validation study) are reported in one section: ‘Results of Case Study-1’ (section 5.4, which follow).

5.3 Results of Case Study-1

There were 28 miniature-kites produced from the UK sample (who accessed four types of kites’ information sources); and 18 miniature-kites were made by the Malaysian students (the comparative groups), 12 from ID-Group and 6 from ED-Group (both samples accessed the kite-poster and internet resources).

5.3.1 Creativity evaluation by researcher [UK vs. Malaysia]

This section shows the researcher’s analysis and evaluation of creativity, utilising archetypal (little ‘c’) and historicist (big ‘C’) judgments. The creative features of the little ‘c’ kites were their colours, patterns on papers/tissues, tails and/or other additional fins, arms or legs that were different and interesting, but the overall physical structures were identical to existing kites. The big ‘C’ kites were very different to existing kites’ designs, and their structures were slightly modified. Examples can be visualised in Table 5.1.

Eighteen (18) kites from UK-ID-Group, 7 kites from Malaysian-ID-Group, and 6 kites from Malaysian-ED-Group showed little ‘c’ creativity. Ten (10) kites (UK-ID-Group), 5 kites (Malaysian-ID-Group) and none from Malaysian-ED-Group showed big ‘C’ creativity (Table 5.5).
In terms of kites’ flying capability: 2 out of 18 (UK-ID-Group), 3 out of 7 (Malaysian-ID-Group), 1 out of 6 (Malaysian-ED-Group) little ‘c’ kites; and 2 out of 10 (UK-ID-Group), 2 out of 5 (Malaysian-ID-Group) big ‘C’ kites could not fly (Table 5.5).

<table>
<thead>
<tr>
<th>Creativity Identified</th>
<th>UK ID GROUP</th>
<th>Malaysian ID</th>
<th>Malaysian ED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(28 Kites)</td>
<td>(12 Kites)</td>
<td>(6 Kites)</td>
</tr>
<tr>
<td></td>
<td>Static Kites Flying</td>
<td>Static Kites Flying</td>
<td>Static Kites Flying</td>
</tr>
<tr>
<td></td>
<td>Ability</td>
<td>Ability</td>
<td>Ability</td>
</tr>
<tr>
<td>Big ‘C’ Creativity (Historicist)</td>
<td>10 8</td>
<td>5 3</td>
<td>0 0</td>
</tr>
<tr>
<td>Little ‘c’ Creativity (Archetypes)</td>
<td>18 16</td>
<td>7 4</td>
<td>6 5</td>
</tr>
<tr>
<td>Identical to Existing (Non-Creative)</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
</tbody>
</table>

Table 5.5
The Results of Creativity Evaluation by the Researcher’s Analysis [UK vs. Malaysia]

5.3.2 Creativity evaluation by students’ paired-comparison [UK vs. Malaysia]

Three (3) out of the UK 6 finalists were big ‘C’ kites (according to researcher’s interpretation), 1 could not fly; another 3 were little ‘c’ kites and all could fly (Table 5.6). Two (2) out of the Malaysian 6 finalists were big ‘C’ kites, 1 could not fly; another 4 were little ‘c’ kites and 2 also could not fly (Table 5.7). These results show the perceptual judgements of creativity from the students, not their consideration of conceptual analysis using any particular criteria.
### 6 Finalists Kites of the UK Students

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>0.50</td>
<td>0.25</td>
<td>0.13</td>
<td>0.11</td>
<td>0.47</td>
<td>0.80</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>0.75</td>
<td>0.50</td>
<td>0.13</td>
<td>0.28</td>
<td>0.55</td>
<td>0.66</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>0.87</td>
<td>0.87</td>
<td>0.50</td>
<td>0.74</td>
<td>0.80</td>
<td>0.89</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>0.89</td>
<td>0.72</td>
<td>0.26</td>
<td>0.50</td>
<td>0.65</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>0.53</td>
<td>0.45</td>
<td>0.20</td>
<td>0.35</td>
<td>0.50</td>
<td>0.62</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>0.20</td>
<td>0.34</td>
<td>0.11</td>
<td>0.25</td>
<td>0.38</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3.75</strong></td>
<td><strong>3.13</strong></td>
<td><strong>1.33</strong></td>
<td><strong>2.23</strong></td>
<td><strong>3.36</strong></td>
<td><strong>4.21</strong></td>
</tr>
<tr>
<td><strong>RANK</strong></td>
<td>2nd</td>
<td>4th</td>
<td>6th</td>
<td>5th</td>
<td>3rd</td>
<td>1st</td>
</tr>
</tbody>
</table>

Table 5.6
UK Students’ Paired-Comparison Results – The Six Finalists
(numbers indicate the decimal fraction of students preferring the kite in this column to the kite in the row)

### 6 Finalists Kites of the Malaysian Students

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>0.50</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>0.46</td>
<td>0.50</td>
<td>0.62</td>
<td>0.54</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>0.46</td>
<td>0.38</td>
<td>0.50</td>
<td>0.58</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>0.46</td>
<td>0.46</td>
<td>0.42</td>
<td>0.50</td>
<td>0.69</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>0.38</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.50</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>6</strong></td>
<td>0.38</td>
<td>0.31</td>
<td>0.31</td>
<td>0.46</td>
<td>0.54</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2.64</strong></td>
<td><strong>2.50</strong></td>
<td><strong>2.70</strong></td>
<td><strong>2.93</strong></td>
<td><strong>3.73</strong></td>
<td><strong>3.50</strong></td>
</tr>
<tr>
<td><strong>RANK</strong></td>
<td>5th</td>
<td>6th</td>
<td>4th</td>
<td>3rd</td>
<td>1st</td>
<td>2nd</td>
</tr>
</tbody>
</table>

Table 5.7
Malaysian Students’ Paired-Comparison Results – The Six Finalists
(numbers indicate the decimal fraction of students preferring the kite in this column to the kite in the row)
5.3.3 **Results of preferred information sources [UK vs. Malaysia]**

The preferences were divided into four categories for the UK study:

a. Sources of inspiration
b. Sources of troubleshooting
c. Sources that would be revisited if re-undertaking the task
d. Helpfulness of kite-information-posters

Whereas, the Malaysian study covered three categories:

a. Sources of inspiration
b. Sources of troubleshooting
c. Helpfulness of kite-information-posters

The UK results of the four sources of information are summarised in Table 5.8, based on the report in Table 5.9:
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Sources of Information

(a) Impact on Inspiration
(b) Impact on Troubleshooting
(c) To Revisit if had more time & when

1. Actual-kites
   some significance  some significance  25% students would revisit
   (61% of them would tend to do that at the start of project; 26% during the process; 13% at the end).

2. Materials-for-kite-making
   little significance  some significance  25% students would revisit
   (63% of them would tend to do that at the start of project; 33% during the process; 4% at the end).

3. Kite-information-posters
   most significance  most significance  21% students would revisit
   (57% of them would tend to do that at the start of project; 33% during the process; 10% at the end).

Faced difficulties flying the kites

Nearly 2/3 of 145 UK students had difficulties flying the kites. Majority overcome the problem by referring to the kite-info-poster and felt it was the most significant source for troubleshooting; some referred back to the actual kite; and did some testing and exploring with other materials; only a few browsed through the internet resources.

(d) Helpfulness

93% of the students agreed that the posters were informative and very helpful, as described in item 4(ii), Table 5.9.

4. Internet-kite-information
   little significance  little significance to some; more felt insignificance  29% students would revisit
   (74% of them would tend to do that at the start of project; 15% during the process; 11% at the end).

Things to look for more carefully online are listed in Figure 5.10.

Table 5.8
Summary of the UK Students’ Preferences of Information Sources
Students’ Kites Design Report (UK)

<table>
<thead>
<tr>
<th>No</th>
<th>Questions</th>
<th>Items</th>
<th>Group Results (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Insignificant</td>
<td>Little Significant</td>
</tr>
<tr>
<td>1</td>
<td>Which sources of information have inspired you the most for your kite design?</td>
<td>(a) Actual kites on display.</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Materials for kite-making.</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Kite-information-Posters</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Internet kite information.</td>
<td>27.6</td>
</tr>
<tr>
<td>2</td>
<td>(a) Did you have difficulties getting the kite to fly?</td>
<td>YES (%)</td>
<td>62.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) If yes, what sources of information helped you to overcome the problem?</td>
<td>(a) Actual kites on display.</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Materials for kite making.</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Kite-information-Posters</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Internet kite information.</td>
<td>41.2</td>
</tr>
<tr>
<td>3</td>
<td>If you did the project again with more time, which resources would you revisit? And when?</td>
<td>(a) Actual kites on display.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Materials for kite making.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Kite-information-Posters</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Internet kite information.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(i) Did you find the information posters about kites helpful?</td>
<td>YES (%)</td>
<td>93.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(ii) If yes, describe how they were useful.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>provide instructions, constructions, and guidelines; useful tips to aid flight.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>help to present technical information on improving kite’s ability to fly.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>using of correct angles; and where to attach lines.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>good images of how different kites have been constructed; good descriptions with photos &amp; illustrations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>show ideas that are flexible &amp; that would work</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>measurement of kite vs. forces acting upon it &amp; positioning of the string; good information on forces &amp; how a kite flies.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>were informative; information on how the kite fly without swinging.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>show forms; provide 3D structure beside 2D for more ideas options; provide ideas of basic frame structure; information on structure &amp; joining techniques; provide structure, balance, and design.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>inspirational, made us start to think about possible ideas; inspiration for design route; inspiration to new design; provide variations &amp; good to get ideas from.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>references to build, so that design could be made to fly.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>basic design information for further experiment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>emphasised the important of lift.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>help visualise existing kites &amp; allow finding ways to improve &amp; make kite to fly.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>show various kites &amp; keys to getting it airborne.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>good information on centre of gravity &amp; general problems.</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.9

Students’ Feedbacks on the Preferences of Information Sources, UK 2009
Students described the following:

- design ideas (2); more inspiring designs (1); inspiration from professional kite-makers; previous designs for ideas generating; inspiration
- flying techniques; technical aspects of kite flying
- pyrotechnics, neons and strobe, lighting
- more variety
- popular designs, designs that effectively fly
- structural help on building kites
- how to make a specific shape of kite
- kite information
- large kite designs that could be scaled down; aerodynamic needs
- how to build robust kite; quirky designs; how to fly properly
- influence, construction techniques + aerodynamics
- more information on how to best make the kite fly (weight and string placing + length)
- more information on structure & physics of flying kites
- variety of kites in the market; ideal size of kite
- kite ideas, more original themes and other possible structures
- tips on better aerodynamics
- various kites structures for more complex design response; kite examples & structures

(Number) – Numbers of people mentioned
The Malaysian results of the two sources of information are summarised in Table 5.10, based on the report in Table 5.11:

<table>
<thead>
<tr>
<th>Sources of Information</th>
<th>(1) Impact on Inspiration</th>
<th>(2) Impact on Troubleshooting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Kite-information-posters</strong></td>
<td>had some significance to 67% students; 33% students thought it was little significance.</td>
<td>13% of them graded the poster most significant; 67% students rated some significance; and 20% students thought it was of little significance.</td>
</tr>
<tr>
<td><strong>Faced difficulties flying the kites</strong></td>
<td>3/4 of 24 ID students and 2/3 of 24 ED students had difficulties flying the kites. Majority overcame the problem by referring to the kite-info-poster and felt it was a significant source for troubleshooting.</td>
<td></td>
</tr>
<tr>
<td><strong>2. Internet-kite-information</strong></td>
<td>was rated most significance by 17% students; 66% of them regarded it as some significance; and 17% students ranked it as having little significance.</td>
<td>was rated most significance by 13% students; 60% students ranked some significance; 14% students rated little significance; 13% students thought it was insignificant.</td>
</tr>
<tr>
<td></td>
<td><em>This result can only be assumed as what they think might work best for them, as they had not been provided with internet facilities during the actual troubleshooting. (Internet was only available after briefing, before they start the designing task.)</em></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.10
Summary of the Malaysian Students’ Preferences of Information Sources
### Students’ Kites Design Report (Malaysian)

<table>
<thead>
<tr>
<th>No</th>
<th>Questions</th>
<th>Items</th>
<th>Group Results (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Insignificant</td>
</tr>
<tr>
<td>1</td>
<td>Which sources of information have inspired you the most for your kite design?</td>
<td>(a) Kite-information Poster</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Internet-kite-information</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>(i) Did you have difficulties getting the kite to fly?</td>
<td>ID (12 Group)</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ED (6 Group)</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) If yes, what sources of information helped you to overcome the problem?</td>
<td>ID (12 Group)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ED (6 Group)</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(a) Kite-information Poster</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Internet-kite-information</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>(i) Did you find the information posters about kites helpful?</td>
<td>ID (12 Group)</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ED (6 Group)</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) If yes, describe how they were useful.</td>
<td>ID (12 Group)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ED (6 Group)</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(a) Use for design ideas</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Help to identify where to fix bridle</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) To know various factors of making the kite to fly</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(d) Provide examples of kite designs, available types</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(e) Describe how to make kite work</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(f) Help to make a flying kite</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(g) Kites technology</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(h) Very useful and easy comprehend tools</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(i) Information provided in a compact form</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(j) Provide proper criteria for kite making</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(k) Help from the designing, making and solving to fly</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.11

Students’ Feedbacks on the Preferences of Information Sources, Malaysia 2010
Overall, more students would choose to access internet-kite-information instead of kite-information-posters, if more time was available. However, if analysed in terms of comprehensive, straightforward, quick access to technological information and immediate impacts on the readers, the results clearly indicated that the posters would be the priority. The impacts comprised:

- inspiration for shapes, forms and other aesthetics values for kite design;
- practical structures and consideration of the centre of gravity for construction; and
- fluid dynamics and stability solutions for troubleshooting.

Effect of kite performance on the creativity analysis (UK-Group only):

<table>
<thead>
<tr>
<th>QUESTIONS</th>
<th>ANSWERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you feel that the results of the static paired comparison evaluation accurately reflect the creativity of the design responses?</td>
<td>Yes (%)</td>
</tr>
<tr>
<td></td>
<td>74.1</td>
</tr>
<tr>
<td>2. Do you think that showing of the kites’ videos would have changed the first set of ‘static’ results?</td>
<td>94.6</td>
</tr>
</tbody>
</table>

Table 5.12
Feedback of Paired-Comparison Reflects Creativity Responses; and Whether Functionality as Part of Creativity

The majority of the students agreed that the method of paired-comparison for visual perceptions could reflect the creativity of the kite-designs (Table 5.12), building on the basis of quick responses to the aspects of eye-catching, colourful, interesting shapes and forms, good quality photographs, good build quality. However, 26% of the students disagreed with this method, as it did not fully measure the creative aspects, because the finalist was selected only based on the aesthetic form without considering their flying ability. Functionality was regarded as an essential aspect of creative design among these students. In addition, the quality of photographs or videos affected the visual judgement of actual kites. It was also not considered fair because not all the kites were compared to each other;
some kites were placed with greater competitors than the others as they were put in different blocks for comparison. Almost all students agreed that kite performances would affect the decision made in the first set of static results (Table 5.12), due to functionality concerns.

5.3.4 Results of validation study (links between VCT > Designing > Creativity/Innovation)

There were 15 kites produced from this validation group (30 PGCE trainees, who only used kite-information-posters for guidance) during their ‘Modelling > Designing > Graphicacy’ workshop activities. Three (3) kites were identified as Big ‘C’ creativity (historicist); and 12 kites showed little ‘c’ creativity (archetypes), and all of them could fly (Table 5.13), based on analysis done in Appendix 5.2.

<table>
<thead>
<tr>
<th>Creativity Identified</th>
<th>UK VALIDATION GROUP (15 Kites)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kites Design</td>
</tr>
<tr>
<td><strong>Big ‘C’ Creativity (Historicist)</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>little ‘c’ Creativity (Archetypes)</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>Identical to Existing (Non-Creative)</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.13
The Results of Creativity Evaluation by the Researcher Analysis [Validation Group in UK]

Most of the trainees agreed that the kite-posters were very informative and helpful in providing basic technological knowledge about the kite-making. This information had inspired them in generating ideas for kite models and helped them in making the kites, particularly about the troubleshooting on balancing and instability problems that they encountered during the kite-workshop. The key messages of the posters that this group perceived are highlighted in red for poster-1 and in blue for poster-2 (Table 5.14), other descriptions of the messages are also listed in Table 5.14.
### Descriptions of Kite Posters by PGCE Trainees, UK (Validation Group):

**Question:** What is your understanding of key messages from the posters?

<table>
<thead>
<tr>
<th>poster 1</th>
<th>feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talk about art/form</td>
<td>2</td>
</tr>
<tr>
<td>HOW &gt; aesthetic; pictorial; basic</td>
<td>2</td>
</tr>
<tr>
<td>Form; Art/Art based; design; style/styling option; aesthetics; graphic of kite</td>
<td>6</td>
</tr>
<tr>
<td>Any shaped kite can fly; soft/flexible and rigid structure can fly</td>
<td>10</td>
</tr>
<tr>
<td>Thinking creatively</td>
<td>1</td>
</tr>
<tr>
<td>Demonstrate different ways of creating kites; how to design your kite; how to make a kite</td>
<td>3</td>
</tr>
<tr>
<td>Inspiring/Images that Inspiring/inspiration/ inspirational by visual</td>
<td>6</td>
</tr>
<tr>
<td>2D &amp; 3D options/Basic 2D &amp; 3D shapes</td>
<td>6</td>
</tr>
<tr>
<td>How symmetry makes things easier; Symmetry is beneficial</td>
<td>5</td>
</tr>
<tr>
<td>The making process</td>
<td>1</td>
</tr>
<tr>
<td>Possibility; rigid &amp; flexible possibilities</td>
<td>5</td>
</tr>
<tr>
<td>Examining variation in concepts</td>
<td>1</td>
</tr>
<tr>
<td>Structure with illustration; explain types of shape &amp; structure; different/various types of structures; various types of kite; kites typologies</td>
<td>8</td>
</tr>
<tr>
<td>2D with frame structure &amp; strength</td>
<td>1</td>
</tr>
<tr>
<td>Provide the dimension</td>
<td>1</td>
</tr>
<tr>
<td>Flexible idea range; ideas which work</td>
<td>1</td>
</tr>
<tr>
<td>How to change properties of kite</td>
<td>1</td>
</tr>
<tr>
<td>Does not glue technical explanation as to why</td>
<td>1</td>
</tr>
<tr>
<td>Not informative compared to poster 2</td>
<td>2</td>
</tr>
<tr>
<td>Form uninformative (as a designer)</td>
<td>1</td>
</tr>
<tr>
<td>Visually better</td>
<td>1</td>
</tr>
<tr>
<td>visual understanding language (no annotations, but info is still addressing same info/areas)</td>
<td>2</td>
</tr>
<tr>
<td>Good for all ages</td>
<td>1</td>
</tr>
<tr>
<td>Should be in Blue colour</td>
<td>1</td>
</tr>
<tr>
<td>to find centre point of balance by sequencing of images</td>
<td>1</td>
</tr>
<tr>
<td>Pictorial Only (pictorial)</td>
<td>1</td>
</tr>
<tr>
<td>Picture; Picture of actual flights; technical info by photos</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>poster 2</th>
<th>feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talk about technology/function</td>
<td>2</td>
</tr>
<tr>
<td>Sciences by graphic</td>
<td>1</td>
</tr>
<tr>
<td>How to get a kite to work/fly; how to fly a kite; technical on how a kite fly; Function&gt;fly well</td>
<td>9</td>
</tr>
<tr>
<td>How to fix problems; sporting problems; problem solving; troubleshooting</td>
<td>3</td>
</tr>
<tr>
<td>Right &amp; wrong ways</td>
<td>1</td>
</tr>
<tr>
<td>Technical; scientific info &amp; details&gt;balance &amp; forces; science of kite making</td>
<td>14</td>
</tr>
<tr>
<td>Practical: construction methods; Engineering; technology</td>
<td>2</td>
</tr>
<tr>
<td>Provide calculation/ measurements/dimensions</td>
<td>3</td>
</tr>
<tr>
<td>Influences&gt;preparing&gt;strength&gt;researched &gt;theory&gt;tested</td>
<td>1</td>
</tr>
<tr>
<td>How</td>
<td>1</td>
</tr>
<tr>
<td>Principles of kite flight performance</td>
<td>2</td>
</tr>
<tr>
<td>WHY &gt;Instruction; details; physics &amp; mechanics</td>
<td>3</td>
</tr>
<tr>
<td>Give technical advice how to find centre of gravity; how to locate cord fixings; how to increase stability; function&gt;gravity</td>
<td>2</td>
</tr>
<tr>
<td>More informative compared to poster 1</td>
<td>2</td>
</tr>
<tr>
<td>Formative (as a designer)</td>
<td>1</td>
</tr>
<tr>
<td>Too informative</td>
<td>1</td>
</tr>
<tr>
<td>Wordy; dull colours</td>
<td>1</td>
</tr>
<tr>
<td>But not without effort.</td>
<td>1</td>
</tr>
<tr>
<td>Should be in Red colour</td>
<td>1</td>
</tr>
<tr>
<td>&quot;problems making kites&quot;</td>
<td>1</td>
</tr>
<tr>
<td>Not structural</td>
<td>1</td>
</tr>
<tr>
<td>Technical data &amp; code&gt;intense&gt;requires concentration&gt;theory</td>
<td>3</td>
</tr>
<tr>
<td>How not to do it</td>
<td>1</td>
</tr>
<tr>
<td>Technical: copy kites</td>
<td>1</td>
</tr>
</tbody>
</table>

(No.) – Numbers of people mentioned.
5.4 Reliability and Validity of the Case Study Results

The reliability of the studied results in Case Study-1 was verified via the triangulation as demonstrated in Figure 5.11. The first data collection was through the survey of literature and found the claims of VCT supporting designing, and hence triggering creativity and innovation. The second data was collected from the experimental kite-designing workshop and evidence of the complex links of VCT, designing and creativity were obtained. The third result was obtained from the Comparative Study from the Malaysian groups, which is in another region and has a different cultural basis.

![Triangulation and Validation Study in Case Study-1](image)

To further validate the triangulation findings, another round of data collection was obtained from the Validation Study of the PGCE, LU group in UK.

Subsequently, another concern rose as to whether the KEPs of VCT applied in the kite-posters had fully achieved the intended value for VCT. Hence, a validation of the application of the KEPs was thought necessary.
This part of the study was further planned within the triangulation of the Case Study-2, which allowed an in-depth investigation and articulation into the criteria of VCT when taken out of a specific context. The previously designed kite-posters were further studied and redesigned (detailed explanation in Chapter 4); and a detail examination using an eye-tracker device was carried out in Case Study-2 (will be explained in Chapter 6).

### 5.5 Summary of Key Findings

Table 5.15 summarises the key findings from the Case Study-1:

<table>
<thead>
<tr>
<th>Key Studies in Case Study-1</th>
<th>Key Findings</th>
<th>Validation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Kite-Designing Workshop in UK</td>
<td>1. VCT contributes to knowledge gained during kite designing. Most UK students stated that it was the most significant source of information because they had learnt that any shaped kites can fly with proper attachment of the bridle based on the centre of gravity, and knowing the forces acting on kite while flying (Tables 5.8 and 5.9); and a large numbers of the Malaysian students stated it had some significance to their knowledge (Tables 5.10 and 5.11).</td>
<td>The validation study had also confirmed the role of VCT in relation to these matters:</td>
</tr>
<tr>
<td>(2) Kite-Designing Workshop in Malaysia</td>
<td>2. Skills can be communicated through VCT. All students’ samples showed performance of designing own shaped of kites without copying the existing kites or those that available for them during the designing task was given. 93% of the UK and 75% of the Malaysian ID students and a minority of Malaysian ME students (33%) agreed that they had solved the kite flying problems by referring back to the posters (Tables 5.8, 5.9, 5.10 and 5.11).</td>
<td>1. Structural aspect of the kite-making</td>
</tr>
<tr>
<td>(3) Kite-Designing Validation Study in UK</td>
<td></td>
<td>2. Fluid dynamics aspect of kite-flying</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Kite-design inspiration</td>
</tr>
</tbody>
</table>

These can be referred to the most frequent mentioned list of messages perceived, as shown in Table 5.14.

Table 5.15 continues on next page...
### Table 5.15
Summary of the key findings in Case Study-1

<table>
<thead>
<tr>
<th>Key Findings</th>
<th>Validation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.</strong> There are suggestions of the communication of values through VCT. Most students were inspired by the kite-posters for their design ideas and had since changed their views about kites after close study on it (Tables 5.8, 5.9, 5.10 and 5.11).</td>
<td>The validation study showed similar outcomes, as indicated in Table 5.13 and Appendix 5.2.</td>
</tr>
</tbody>
</table>

| Key Studies in Case Study-1 |
|-----------------------------|-----------------------------|
| (1) Kite-Designing Workshop in UK | (2) Kite-Designing Workshop in Malaysia |
| (3) Kite-Designing Validation Study in UK |
Chapter 6  Case Study-2

[KEPs of VCT]

Chapter Overview

Chapter Six describes how the second case study that had been designed to test the KEps of VCT within an experimental context was conducted. It explains how the results were obtained and the data gathered and interpreted. Detailed case study design, selection of visuals, and data collection methodologies are illustrated. Issues concerning the reliability and validity are discussed. Figure 6.1 illustrates how Chapter Six fits into the structure of this thesis.
6.1 Case Study-2 Design

Toward the end of the Case Study-1 (CS1), a number of concerns arose, whether the KEPs of VCT could work and whether they had effectively been used to enhance the communication of the kite-posters. Thus, it was decided that a series of validations regarding the KEPs should be carried out, using an eye-tracker device, and by analysing current practices and the visual tools that have been successfully in assisting the development of technology since the Renaissance and industrial revolution. With these bases, Case Study-2 was plotted to investigate and articulate the criteria for the KEPs of VCT when taken out of a specific context.

6.1.1 Application of the KEPs of VCT

The KEPs of VCT were derived from the literature survey in the first place. The KEPs were then applied in the design of the kite-posters, as a visual-technological-information (VTI) for CS1, and also with the intention to test the workability of the KEPs. The kite-posters were further improved after obtaining some findings from CS1 initial pilot testing using the eye-tracker, and initial comparative analysis of the 16th Century visual.

6.1.2 Validating the KEPs through a lens of science

The first stage of the validation was an experiment using an eye-tracker device to capture what a reader sees and understood about the kite-posters. This scientific method allowed the KEPs to be described in terms of the intentions of the originators of the visuals to be validated against the interactions as experienced by the readers. Therefore, it allows the opportunity to evaluate the effectiveness of certain visuals; particularly for the visual that had already showed that it (the kite-poster) represents good practice in CS1. A further analysis through comparison with historical good practice of visual information design (the work of da Vinci, 1500, taken from Ferguson, 1993) was conducted. Both visuals, da Vinci’s (1500) and the author’s kite-poster (Beh and Norman, 2009), as in Tables 6.1, were trialled for the eye-tracking test in order to gather the readers’ responses toward the KEPs.
VCT Principles:
**KEP-3: PRECISE > TRUTH**

**Key criteria of selection:**
Communicates designed or studied details in order to inform about extensive technological aspects or features for further understanding and inspiration.

**Current Examples**
(have evidence of effective impact in communication)

---

**(A) Kite-VTI**
*Beh, 2009 [adapted from Key Stage 3 (for 11-14 year olds) Kite Resource Pack, Norman and Cubitt, 1999]*

**VS**

**(B) Ratchet Device**
*Leonardo da Vinci, 1500 (Ferguson 1993, p. 88)*
These 2 visuals were put together for comparison because they were found to fit into the categories of KEPs, in terms of: KEP-1: COMPARE > RELATIONSHIP; and KEP-3: PRECISE > TRUTH. Visuals A and B (Table 6.1) were selected for the means of communicating designed or studied details, which were about informing the extensive technological aspects or features for further understanding and inspiration purposes.

6.1.3 **Validating the KEPs by comparing the visual information of the 16th Century and current practices**

In order to be more certain about the validity of these KEPs, they were further analysed through comparison with other good practices of visual information from the past and those in current practice. Four visual representations were selected for this validation. They include 2 from historical evidence (Besson, 1578; d'Ocagne, 1862) taken as good examples from Ferguson (1993); and another 2 from current representations which have shown some evidence of effective impact in communication (Storer, 2005; Lofthouse and Bhamra, 2005), Tables 6.2 and 6.3.

These visuals were selected because they supported designing and innovation, and that they could be set into the categories of the KEPs of VCT: 1) COMPARE > RELATIONSHIP; and 2) FORM > FUNCTION. Visuals C and D (Table 6.2) were selected with the intention of allowing the viewers to compare relationships and the interaction between humans and technologies, which were used to communicate extensive messages about products, processes, proportions, materials, etc. Figures E and F (Table 6.3) were selected based on their ultimate use as aids or tools to guide further design decisions.

This past and current visuals analysis was then carried forward to scientific assessment by using eye-tracking methods to determine viewers’ reading patterns corresponding to the KEPs applied. Within this study, KEPs were able to be further verified. Thus, it was an ideal experiment to be selected for the validation of KEPs of VCT in Case Study-2 (CS2) triangulation.
VCT Principles:
**KEP-1: COMPARE > RELATIONSHIP**

**Key criteria of selection:**
Comparing relationships and interaction between humans and technology; communicating extensive messages about products, processes, proportions, materials, etc.

<table>
<thead>
<tr>
<th>Current Examples (have evidence of effective impact in communication)</th>
<th>Historical Evidence (Ferguson, 1993)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C) Sustainable Design Poster <em>(Storer, 2005)</em></td>
<td>(D) Manual up-and-down sawmill <em>Jacques Besson, 1578 (Ferguson 1993, p. 79)</em></td>
</tr>
</tbody>
</table>

Table 6.2
Rationale of the Visuals Selection for Validating KEP-1
**Chapter 6 Case Study - 2**

**VCT Principles:**

**KEP-2: FORM > FUNCTION**

**Key criteria of selection:**

Used as an aid or tool to guide further design decisions.

**Current Examples**

( have evidence of effective impact in communication)

**Historical Evidence**

(Ferguson, 1993)

---

**Table 6.3**

Rationale of the Visuals Selection for Validating KEP-2

---

(E) Ecodesign Web for Isotonic drink bottle concept

(Lofthouse and Bhamra, 2005, adapted from the LiDS-wheel, Hemel, 1995)

(F) Nomogram

Maurice d’Ocagne, 1862 (Ferguson 1993, p.151)
6.2 Data Collection Methodology

The case study of validating the KEPs of VCT consists of 3 main phases of activities as shown in Figure 6.2.

PHASE-1: Design and redesign kite-posters using the KEPs of VCT

PHASE-2: Eye-tracking the Kite-Posters to validate the KEPs

PHASE-3: Validating by analysing the 16th Century versus current visuals by conventional and eye-tracking methods

Figure 6.2
Flowchart of Validating the KEPs of VCT for Case Study-2
6.2.1 **PHASE-1: Design and redesign kite-posters using the KEPs of VCT**

The design and redesign of the kite-posters were explained in Chapter 4. This chapter only provides some brief summary and key considerations of CS2.

The KEPs of VCT were used as a guide to design the two posters, as in CS1. These posters were then modified from two-into-one questionnaire format (by keeping the key aspects of the KEPs) for Malaysian comparative study; because it was thought that the format was more suitable for overseas purpose. However, the CS1 results suggested that the initial red kite-poster played an essential role in emphasising key message of the kite’s structure.

Additionally, before setting up the phase-2 eye-tracking for the posters, a pilot test study of using the eye-tracking device was carried out using one of the posters (the cyan-poster). The initial results also confirmed the findings of the CS1 about the KEPs application. Therefore, the kite-posters were further improved, and one of the 16th Century visuals (Visual ‘B’ in Table 6.1) was also used as guide to improve the final version of the kite-VTI. This selected historical visual was used as it was identified as having been supporting designing and innovation since the Renaissance (as explained in section 6.1.2 and Table 6.1).

6.2.2 **PHASE-2: Eye-tracking the kite-posters to validate the KEPs**

A pilot experiment was setup using an eye-tracker device that attached to a bicycle helmet and was connected to a computer workstation. A total of 3 participants volunteered in the pilot test, which was done one person at a time in about 15 minutes slot for each, supposedly, but some ended after about 30 minutes. Each participant of the experiment was seated and positioned in front of the cyan-kite-poster, as shown in Figure 6.3. The distance of the participant and the poster was about 300mm apart; which has been considered as a decent reading distance by the A3 size of the poster. By wearing the helmet with the attached eye-tracker camera, which was calibrated for every individual’s eyes, the participants had to hold their head as still as possible during the viewing and recording process.
The participants (with similar background of ID education) were asked to describe ‘how they read’, more specifically, ‘how they visually perceive’ the poster. The viewing process was recorded by the device, capturing the participant’s visual reading patterns; and their descriptions were also noted in order to trace any significant responses toward the KEPS applied.

After the pilot, an initial test of eye-tracking was done with 1 participant, and the visual used was the red and cyan posters that were placed side-by-side. The red-poster was brought back in this test as it was determined as played very essential role in providing key message of the structural aspects of the kite technology.

The third version of the kite-VTI was then emerged based on those previous test studies, and was tracked again via eye-tracking together with the comparative analysis with the da Vinci’s (1500) drawing. The setup for this test was modified (explained in section 6.2.5), where these 2 visuals were shown via a PowerPoint slide projection on the wall for viewing; whilst, the participant was set about a meter away from the projection (about 5 x 5 feet in size), as shown in Figure 6.4.
The comparison of the 2 visuals was put into 3 sets of test for the data gathering, as follows:

1. Visuals without language explanation
2. Visuals with language explanation (accompanied by captions and interview prompts)
3. Visuals placed in three pairs for comparison

The recording system involved a small camera device and an audio recorder. The audio recorded the interview prompts and responses. The camera was attached to a bicycle helmet that was put on the viewer, and was calibrated for the individual participants’ eyes and recorded what the viewer saw. Eyes movement while reading the visuals were captured by the device on the helmet.

Five participants took part in this main test, and they remained anonymous in all published outcomes. However, some personal details were gathered for research data, particularly the participant’s academic background or prior knowledge, cultural background, age and gender groups, as these factors may or may not influence the research outcomes. Loughborough University’s Ethical Clearance Checklist (Appendix 6.1), Briefing and Consent (Appendix 6.2) for Participants’ procedures were followed.
Set-1 Experiments: Visuals without language explanation

Participants were asked to describe what they ‘see’ in each of the 2 visuals projected. Due to the experience gained during eye-tracking in the pilot and initial exercises, some guiding questions (Figure 6.5) were drafted to use as prompts during this set of tests, in case, for example, the researcher needed to determine or clarify why viewers were looking at some spots but not others, or have a particular pattern of descriptive results (these had been occurred during the pilot and initial experiments). However, these questions were not used in the main study because the participants’ responses in this phase seemed quite sufficient and clear for the analysis of this aspect of the study. They are included in Figure 6.5 of this report in order to clarify its scope.

Possible questions for interview prompt in Set-1 experiment:

Questions related to ‘Spotting’
You seem to scan back and forth a few times from spot A to spot B,

1. Can you explain why you did that?
2. What were you thinking at that moment?
3. What have you gained/understood from that spot?
4. Is the action of looking back and forth helping you to understand more/the message?

Questions related to ‘Duration’
You have stared at a spot for quite some time,

1. What have you seen?
2. What were you trying to understand?
3. Is there any other message you think it might imply?

Questions related to ‘Sequence’ (Scan path)
You have read the poster from e.g. right to left (a certain pattern),

1. Can you explain why you did so?
2. I’ve noticed that you have changed the pattern of reading the visual, please describe your findings after doing so.

Set-2 Experiments: Visuals with language explanation

Participants were asked to describe what they ‘understood’ in each of the same 2 visuals projected, only this time captions were added to the visuals. Additionally, some semi-structured questions were used as prompts during the viewing.
This was to help those participants who needed some hints to guide them to describe what they have seen and understood, what they were not so clear about, or what they have not yet stated in the first set of experiment. The semi-structured questions were based on four focus areas: 1) Obvious message; 2) Obvious details; 3) Hidden or interpreted details; and 4) Interpreted or inspiration message. The questions correspond to the visuals as illustrated in Table 6.4.

<table>
<thead>
<tr>
<th>Visual-A</th>
<th>Visual-B</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Visual-A image" /></td>
<td><img src="image2" alt="Visual-B image" /></td>
</tr>
</tbody>
</table>

1. **Obvious Message**
   - What is the message of these posters?
   - What do you see in the drawing?

2. **Obvious Detail**
   - What are the forces acting on the kite while flying?
   - What are the main elements in this device?

3. **Hidden/Interpreted Detail**
   - How is a kite balanced?
   - Can you describe how the device operates?

4. **Interpreted/ Inspiration Message**
   - Do these posters inspire you to have new ideas for kite design? In what way?
   - What are the factors that you need to consider if you were preparing to build a device of this kind?

**Table 6.4**

Semi-structured Questions for the Interview Prompt in Set-2 Experiment for Visuals A and B

The visual test of this phase required the viewers to respond to ‘what they have seen’ and describe ‘what they have understood’. These terms were believed easiest to understand regarding what was needed to be done by most people from various cultural and language backgrounds, as compared to the terms used in the pilot test (where the participants were asked to describe ‘how they read’ or ‘how they visually perceive’ the poster).
Set-3 Experiments: Visuals placed in pairs for comparison

After viewing the individual images, the same 2 visuals from the Set-2 experiments were placed in pair for comparison. This was intended to allow the participants to have another chance to compare the similar relationships or intentions of each set of representations, if they had not seen the relationship in the first place. The participants were asked to describe any similarities in the ways this pair of images communicated.

6.2.3 PHASE-3: Validating the KEPs via analysis of the past and current visual representations

The examination of the KEPs through kite-VTI and the 16th Century drawing using eye-tracking (PHASE-2 study) obtained useful objective data, where the effects of the KEPs was able to be captured. With this finding, it was decided that further investigations concerning other categories of the KEPs were needed. Moreover, this next step of investigation could be used to validate the evidence obtained from the kite-VTI and da Vinci’s drawing. Therefore, another 2 pairs of the past and current visuals were selected for this validation investigation.

The selected 4 visuals were identified as some evidence has suggested that they supported designing and innovation, and had evidence of that they represent good examples in practice of their time. They were compared and analysed in pairs and were found to have possessed similar application of KEPs by the researcher. An eye-tracking experiment was used to test whether other readers would react and agree to the application of KEPs by their interaction and responses. The viewing process was recorded, capturing individual’s visual reading patterns (same techniques and procedures used for Visuals A and B) in order to help test the principles of VCT applied on those representations. The semi-structured questions were as illustrated in Table 6.5. The same 5 participants who took part in the eye-tracking test for Visuals A and B were participated in this validation study.
## Table 6.5
Semi-structured Questions for the Interview Prompt in Set-2 Experiments for Visuals C, D, E and F

<table>
<thead>
<tr>
<th>Visual-C</th>
<th>Visual-D</th>
<th>Visual-E</th>
<th>Visual-F</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Visual-C" /></td>
<td><img src="image" alt="Visual-D" /></td>
<td><img src="image" alt="Visual-E" /></td>
<td><img src="image" alt="Visual-F" /></td>
</tr>
</tbody>
</table>

### 1. Obvious Message

| What is the message of this poster? | What does this machine do? | What is the purpose of this diagram? | What is the purpose of this diagram? |

### 2. Obvious Detail

| What are the main stages of the life cycle of a product? | What are the key elements of the machine? | How does the colour scheme work? | When the r.p.m = 4,000 and torque = 400 units, what is the brake horsepower (BHP) of the engine? |

### 3. Hidden/Interpreted Detail

| What are some of the key strategies to improve the environmental performance? | What does the operator (human figure) do in the drawing? | If you were asked to aim for “reuse, reduce and recycle”, what does the diagram suggest you could do? | If the r.p.m stays the same, what could happen to the torque and BHP? |

### 4. Interpreted/Inspiration Message

| Does this poster inspire you in some way? How? | What are the factors that you need to consider while preparing to build this machine? | How could you use this tool to improve your designing (from an ecodesign perspective)? | If you were to design a less powerful engine, what could happen to the r.p.m, and torque? |
6.2.4 **Sampling and recordings**

There were 3 participants, with similar background of ID education, who volunteered in the pilot test experiment of eye-tracking on the kite-posters. One (1) participant (P) in the initial test of the kite-VTI, and the main study of comparing Visuals A and B had an academic background of Design and Technology (P1). Four (4) participants completed the main eye-tracking experiment. Their academic backgrounds were: Materials Sciences and Engineering (P2); Art and Design/Fine Art (P3); Industrial Engineering (P4); Industrial Design (P5). They were a purposive sample in that they represent particular academic categories of students. They were also selected for their different cultural backgrounds in terms of where they grew up: two from the UK; one from Cyprus; one from Singapore; one from Mexico; and they were asked for their learning preferences for an initial comparative study.

During the main experiment, two of the respondents’ recordings were captured with some missing eye-scanning statistical data. This was caused by missing out a step of saving the second data file. Therefore, it was not possible to generate the scanning path patterns. However, the raw sources of eye-tracking video (with eyes fixations), and the descriptions of what they have seen and perceived were safely recorded and this data could still be used for further analysis. The other three respondents’ recordings were captured fully, and were able to be used for the full scanpaths analysis.

6.2.5 **Piloting, issues and changes for Case Study-2**

Four volunteers took part in the pilot testing with the eye-tracker device, and helped through strategising the setup of the experiment. Among the four volunteers, one of them wore glasses.

**Setting up the device and visuals**

In the test, a sample visual representation was placed on an unused monitor screen, so it was to be read from about 300mm distance. Whilst, another set of visual was posted on the wall, so it was meant to be read from about a metre away distance.
In the case of the visual placed on the monitor screen, the eye-tracker control workstation was placed next to each other. As for the visual on the wall, the control station and the participants faced different directions. The device camera was calibrated according to the individual participant’s right eye (assuming both eyes coordinate the same way). The experiment was setup in a small (about 2.5 meter square feet) room which contained many other pieces of equipment.

**Issues or problems occurred during the pilot testing**

This section reports 2 main areas of concerns, they are about:

- The setting up of the equipment and its related issues or problems while operating it. This also included any parts of the devices and the participants’ intentional or unintentional reactions while having part of the equipment attached to them.

- The feedback from the participants, as this could help structuring potential questions or verbal clues to guide the participant for describing the poster. This was to be used if the participants had problems in giving responses to what they perceived from the visuals.

**In terms of setting up the equipment**: a number of incidences occurred, making the experiment take up more time than planned, these included:

1. Control station being placed next to the participant’s viewing area created a distraction for the study; because all the participants’ were constantly looking back-and-forth from their screen to the control station. This was because the workstation displayed on the screen how their eyes appeared and how they moved around, and what they looked at.

2. The atmosphere in a small room with many other pieces of equipment made the participants feel uncomfortable or curious, thus, making them look around (meaning, their eyes were always moving around the room during the test). This caused the recorded eye-fixations and scanpaths to frequently run out of scene (the recorded area).
3. Participants’ head movements caused the recorded video to have lots of movements or jerks.

4. The participant with glasses made the process of calibrating his eye very difficult.

5. Some people’s eyes needed more lighting to calibrate the device camera than others.

6. The eye-tracker only captured the visual movement of eye; thus an additional device was needed to capture participants’ responses in term of their descriptive views and perceptions.

In terms of participants’ feedbacks: 2 participants shared the same views regarding the handling of the eye-tracking experiment, and suggested to the researcher to provide more details about the intention of the experiment and viewing the poster. This was particularly related to what to be expected by reading the poster, e.g. they gave, “I want to improve the graphic design aspects of the poster, so your help in giving feedbacks on the graphics and visual presentation were be needed; or can you please talk about the colours or images aspects based on your expertise in design field?” To them, this preparation could provide them more clues as to what to focus on the poster and as to what said about it.

Improvement and changes for the actual experiment

In terms of the equipment and its setting up:

1. The position of the viewing area and eye-tracker control station were set in different directions, so the participant would not be able to see the control monitor, unless they totally turned their head. Therefore, the PowerPoint slides projection onto the wall was decided to be used for the actual experiment.

2. The whole setup was moved to a wider and empty space, where partition boards were used to enclose the experiment area and block unnecessary things from view.
3. A more comfortable chair with a higher back support was found in order to reduce the movement of head.

4. Volunteers were recruited and particularly those who did not wear glasses.

5. Additional light was used to brighten up the space in order to be able to calibrate the eye to the device camera for certain people.

6. Audio recording was included for the actual test.

In terms of the participants’ feedbacks: the researcher disagreed with the suggestions given by the 2 participants about providing too direct and detailed information about the intention of reading the poster. This was because by doing so, it would defeat the whole purpose of spotting and capturing the actual activity of the eyes and their minds functioning in processing and understanding the visual information. Moreover, the function of a poster should be ascertained on the spot, and to be access by viewers without any verbal guidance. The graphic elements would take full responsibility and function to explain themselves. These were the key aspects which had to be tracked and evaluated from the CS2 in order to validate the KEPS.

Nonetheless, the researcher agreed in providing a general explanation about the eye-tracking practice, in order to prepare the participants for the experiment. This included:

1. To inform the participant that the experiment intention was about capturing their reading patterns on visual information.

2. A poster would be given to view, and the participants were expected to describe ‘how they read and perceive’ the poster.

By collecting the data from item number (2) above, the study already could obtain sufficient details concerning the graphic design aspects; and which the KEPs applied could be assessed.
6.3 Results of the Pilot and Initial Eye-Tracking on Kite-Poster

The reading patterns (Table 6.6) obtained from the eye-tracking on the kite-poster from 3 volunteers is reported in this section, with a table illustrating the summary of those results (Table 6.7). This format was intentionally to ease the comparison between the similarity and differences of reading patterns (or mapping sequences) of the 3 volunteers, in terms of images and text that they perceived from the poster. In the report, the term ‘AOI’ refers to the ‘area of interest’ (AOI-1 to AOI-4), as shown in Figure 6.6.

![Figure 6.6 Format of the Kite-Poster Design](image-url)
Table 6.6
Kite-Poster Readings of 3 Participants: Eye-Tracking Sequence Chart

<table>
<thead>
<tr>
<th>Description of AOI</th>
<th>Participants' Visual Mapping Sequence on Kite-Poster</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participant-1 (P1)</td>
</tr>
<tr>
<td></td>
<td>AOIs</td>
</tr>
<tr>
<td></td>
<td>AOI-1</td>
</tr>
<tr>
<td></td>
<td>AOI-2</td>
</tr>
<tr>
<td></td>
<td>AOI-3</td>
</tr>
<tr>
<td></td>
<td>AOI-4</td>
</tr>
<tr>
<td>Timeline</td>
<td>Timeline</td>
</tr>
</tbody>
</table>

[Diagram of Kite-Poster with AOIs marked and timelines for each participant]
### Description of AOI

<table>
<thead>
<tr>
<th>Images</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both P1 and P2 had the same eye-scanning sequence, which were from AOI-1 to AOI-2, then AOI-3 to AOI-4. Very quickly, both of them shifted their viewing sequence and read from AOI-1 to AOI-3, then AOI-2 to AOI-4. They did that in order to compare and make connection of relationships, so comprehend the visual information.</td>
<td>After scanning the overall groups of images (involving the 4 AOIs), P1 and P3 read the text in the following sequence: big title &gt; subtitles &gt; illustrations &gt; annotations &gt; big title again &gt; illustrations &gt; subtitles &gt; annotations &gt; and ended with big title.</td>
</tr>
</tbody>
</table>

| Table 6.7 Summary of the Eye-Tracking Results: Mapping Sequence of Images and Text on the Kite-poster for 3 Participants |  |  |

*Note: Only one of the kite posters was tested via eye-tracking, because the 2 posters applied the same format and used the same KEPs as the designing guideline. Thus, it was thought to be sufficient for one set of data to be collected.*
6.3.1 Participants’ visual mapping sequence on poster from the pilot study

- Both P1 and P2 started their eyes scanning the poster from AOI-1 to AOI-2, and then from AOI-3 to AOI-4. However, in a very quick moment, both of them changed their viewing patterns, and started reading AOI-1 to AOI-3, and then AOI-2 to AOI-4 (‘reading’ is used at this point because they spent more time on those AOIs and started to describe how they read the poster). When asked them why they followed that reading sequence, both explained that at first glance, they read from AOI-1 and move down to AOI-2; but they were not completely sure how to make the kite lift successfully.

They only could tell that it had something to do with wind forces. Therefore, they moved on to read AOI-1 again, and then to AOI-3; to AOI-2 and AOI-4; and back again to AOI-1 and AOI-2. By reading the poster in the aforementioned sequence, they could then compare the visuals in those sections, and start to make some connections and build up their relationships. They concluded that the stories were becoming significant and thereafter allowed comprehension. From reading the AOI-3 (as a basic technique for bridle-attachment) and then to AOI-4 (as additional techniques of adding tails) answered the doubts that they had previously, which was by applying the techniques depicted in AOIs 3 and 4, a kite could be lifted based on the wind force directions.

- After scanning the overall groups of images (involving the 4 AOIs), P1 and P3 read the text in the following sequence: big title > subtitles > diagrams/illustrations > annotations > big title again > diagrams/illustrations > subtitles > annotations > and ended on the big title. This sequence also aided P1 and P3 to understand the overall information on the kite-poster.
6.3.2 **Key findings of visual mapping sequence in relation to the KEPs in the pilot**

The results of visual mapping sequence attained from the 3 participants matched the intention of the kite-poster design, which applied the KEPs of VCT. The findings included:

- Reading the AOI-1 and AOI-2 to gain some awareness in terms of kite-lifting and the facts of wind-force on kite, but not fully comprehend (Tables 6.6 and 6.7). [NB: the graphic design intentions for clues and provoking interest to find out more; described in detail in section 4.2.1 (item number 2), Chapter 4]
- Reading the AOI-3 and AOI-4 to obtain the techniques and additional solutions aspects for kite-stability in order to help kite-lifting (Tables 6.6 and 6.7). [NB: the graphic design intention for ‘how-to-do’ aspect; described in detail in section 4.2.1 (item number 2), Chapter 4]

These 2 key findings showed that the FORM or structure of the kite-poster FUNCTIONed, as it was able to guide viewers in navigating the information within the poster. This corresponded to the KEP-2: Unity of FORM to accentuate FUNCTION.

- Reading the AOIs from AOI-1 > AOI-2 > AOI-3 > AOI-4; or AOI-1 > AOI-3 > AOI-2 > AOI-4 would attain the same understanding (Tables 6.6 or 6.7), as long as the viewer could be able to compare the visual elements depicted, and make connections and build relationships among them to achieve understanding. This matched the KEP-1: Facilitating COMPARISON to reveal CONNECTIONS and RELATIONSHIPS.

- All 3 participants could describe the details of how to make a kite to fly and resolutions for troubleshooting flying difficulties and instability. This implied that the poster achieved the KEP-3, by having PRECISION of data to communicate or inform the TRUTH.

These key findings also became one of the key aspects for the redesign consideration for the kite-poster (the third version of kite-VTI) used for the main study (explained in section 4.2.1, Chapter 4).
6.3.3 Initial eye-tracking findings of Visuals A and B

The eye-tracking study was to confirm that what the participants said was in agreement with what they were viewing, and the images they have processed in their mind’s eye to understand the messages. Figure 6.7 is the raw video recording sources of the participant’s viewing scanpaths. Dots and lines in orange colour on the images (Figure 6.7) are the scanpath traces, indicating the eyes’ movements over the area of interest (AOI). These raw sources were difficult to analyse as the movements were all in milliseconds, making it too fast to simply observe the differences. Thus, the video sources were transferred into snapshots, capturing frame-by-frame (shown in Table 6.8/6.9) in order to ease the identification of the respondents’ eyes movements, patterns and their fixations on the AOI. These scanpaths were then analysed in parallel with the respondents’ protocol transcripts.

Tables 6.8 and 6.9 show the participant’s eye-scanning-path, and the descriptions on how she understood the messages on the Visuals A and B. The key findings were:

- P1 highlighted the key message of ‘any shaped kite can be made to fly’ and about the kite’s structures in the red section of the poster.
- P1 also identified almost all of the kite’s technological details depicted in the poster precisely and accurately, either with or without prompts questions. (Full recorded analysis is in Annexes attached in DVD)
The 2 aspects of the participant’s responses showed that the reader was able to identify the overall form of the kite structures or the ‘whole’ aspect of an object; and details or ‘individual parts’ that makes up the whole.
This implied that the visual representation had successfully achieved the intention, as stated in KEP-1: COMPARE to reveal CONNECTION and RELATIONSHIP (about the connections and relationships of ‘whole’ and ‘parts’); and KEP-3: PRECISION of data to communicate ACCURACY or TRUTH for the almost accurate pieces of information.

Prompts (P):
6.1 What do you see in the drawing?
6.2 What are the main elements in this device?
6.3 Can you describe how the device operates?
6.4 What are the factors that you need to consider if you were preparing to build a device of this kind?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td>Assembly on the left and disassembly on the right for a mechanism.</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td>Something that is moving up-and-down, while the wheel rotates</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td>The teeth seem to stop the thing from rotating the other way.</td>
</tr>
</tbody>
</table>

Table 6.9
Scanpaths and Protocol Transcripts of Visual-B from P1
6.4 Results of the Main Study of Kite-VTI and da Vinci’s Drawing

The report in this section focuses on the key elements that made the readers understand the visual information which directly related to the KEPS applied. The report details include capturing the eye scanning paths (not in a continuous sequence of the whole journey, rather a continuous sequential pattern of the understanding of a particular message). Also, the eye-scanning paths captured and reported, directly corresponded with the participants’ protocol transcripts in understanding of the key messages, which related to the KEPS. The complete analysis results of the overall journey for all participants can be found in Annexes attached in DVD.

6.4.1 Results of kite-VTI (Visual-A) and its links to KEPS of VCT

Tables 6.10 and 6.11 show the patterns of eyes’ scanning paths on Visual-A by 2 participants, and their descriptions on how they understood the messages. This was used for the analysis and reports in this section. The key findings from the participants were:

- P2 and P3 were able to identify all of the kite’s technological details depicted in the poster precisely and accurately, either with or without prompts questions.
- They were also able to highlight the key message of ‘any shaped kite can be made to fly’ and about the kite’s structures in the red section of the poster.

These 2 aspects showed that the readers were able to identify the overall form of the structure or the ‘whole’ aspect of an object; and details or ‘individual part’ that makes up the whole. This implied that the visual representation had successfully achieved the intention, as stated in KEPS-1: COMPARE to reveal CONNECTION and RELATIONSHIP (about the connections of ‘whole’ and ‘parts’); and KEPS-3: PRECISION of data to communicate ACCURACY or TRUTH for the accurate pieces of information.
### Prompts (P):
- **5.1** What is the message of these posters?
- **5.2** What are the forces acting on the kite while flying?
- **5.3** How is a kite balanced?
- **5.4** Do these posters inspire you to have new ideas for kite design? In what way?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1.png" alt="Scanpath Frames" /></td>
<td></td>
<td>The poster is about the importance of forces acting and to find the centre of gravity. It is to show the user how to design kite.</td>
</tr>
<tr>
<td>3.</td>
<td><img src="image2.png" alt="Scanpath Frames" /></td>
<td><strong>P5.3 How is a kite balanced?</strong></td>
<td>A kite is balanced by direction of wind, weight of kite, and...centre of gravity is also very important factor for balancing and stability. It also can balance a kite by adding tails, wings or fins. So, it is possible to design any shape of kite that can fly, provided we can find the centre of gravity and also with the enhancement of tails, which should be stabilising while up in the air.</td>
</tr>
</tbody>
</table>

Table 6.10
Scanpaths and Protocol Transcripts of Visual-A from P2
### Prompts (P):

6.1 What is the message of these posters?
6.2 What are the forces acting on the kite while flying?
6.3 How is a kite balanced?
6.4 Do these posters inspire you to have new ideas for kite design? In what way?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1" alt="Scanpath Frames" /></td>
<td><strong>P5.1</strong> What is the message of these posters?</td>
<td>Red section describes 4 differences structures of kite. It is about making a kite. There are several possibilities for building a kite, how to attach the line, about the shapes, troubleshooting etc.</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2" alt="Scanpath Frames" /></td>
<td><strong>P5.2</strong> What are the forces acting on the kite while flying?</td>
<td>Blue section about the dynamic of the kites and how wind acts on the kite while flying. Lift force, combine force, drag force and wind.</td>
</tr>
<tr>
<td>3.</td>
<td><img src="image3" alt="Scanpath Frames" /></td>
<td><strong>P5.3</strong> How is a kite balanced?</td>
<td>It has a centre of gravity and the line needs to be attached along the centre of gravity with the line called bridle.</td>
</tr>
<tr>
<td>4.</td>
<td><img src="image4" alt="Scanpath Frames" /></td>
<td><strong>P5.4</strong> Do these posters inspire you to have new ideas for kite design? In what way?</td>
<td>Yes, it would help a lot for kite design ideas. It said that ‘any shape can fly’ but I would imagine that a symmetrical one much easier to build to fly, and all the examples are more symmetrical.</td>
</tr>
</tbody>
</table>
6.4.2 Results of da Vinci’s drawing (Visual-B) and its links to KEPs of VCT

Tables 6.12 and 6.13 show the 2 participants’ eye-scanning path patterns and their descriptions on how they understood the messages on Visual-B. The key findings from the participants were:

- The participants recognised the drawing consisting of assembled and exploded drawings of a device. One presented the whole construction and the other was an exploded view of the individual parts of the device.

- They were able to list out the key elements building up the device; and also could describe the operation of the device from the drawing.

These 2 aspects showed that the readers were able to identify the overall form of the device as a ‘whole’ as an object; and details or ‘individual part’ that makes up the whole piece of the device. This implied that the visual representation had successfully achieved the intention, as stated in KEP-1: COMPARE to reveal CONNECTION and RELATIONSHIP (about the connections of ‘whole’ and ‘parts’); and KEP-3: PRECISION of data to communicate ACCURACY or TRUTH for the accurate pieces of information to build up the whole device.
### Prompts (P):

12.1 What do you see in the drawing?
12.2 What are the main elements in this device?
12.3 Can you describe how the device operates?
12.4 What are the factors that you need to consider if you were preparing to build a device of this kind?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image" alt="Scanpath Frames" /></td>
<td><strong>Assembled drawing on the left and exploded drawing on the right.</strong>&lt;br&gt;<strong>On the left, I reckon that all parts of elements being put together to become a device.</strong>&lt;br&gt;<strong>Exploded drawing shows individual part of elements that used to assemble the device on left.</strong></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td><img src="image" alt="Scanpath Frames" /></td>
<td><strong>P6.2 What are the main elements in this device?</strong></td>
<td><strong>The main elements consist of the poplar wheels...</strong>&lt;br&gt;<strong>... the teeth on the wheels.</strong></td>
</tr>
</tbody>
</table>
Prompts (P):
6.1 What do you see in the drawing?
6.2 What are the main elements in this device?
6.3 Can you describe how the device operates?
6.4 What are the factors that you need to consider if you were preparing to build a device of this kind?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1.jpg" alt="Image" /></td>
<td>6.1 What do you see in the drawing?</td>
<td>2 drawings of a design for a ratchet device which operated by a pulley system. One is constructed and ... ...the other is deconstructed.</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2.jpg" alt="Image" /></td>
<td><strong>P6.2</strong> What are the main elements in this device?</td>
<td>The main elements are the frame, the pull which is pulled by the weight on the rope or string and the 2 cogs and the axles in the middle.</td>
</tr>
<tr>
<td>3.</td>
<td><img src="image3.jpg" alt="Image" /></td>
<td><strong>P6.3</strong> Can you describe how the device operates?</td>
<td>The weight pulls the string... ...which turns and pushes the cogs in either directions using the cog at the end, and the round cogs were made with axles... Oh...no the enlarge section of the teeth at the lower right corner show that the device can only turn in one direction.</td>
</tr>
</tbody>
</table>

Table 6.13
Scanpaths and Protocol Transcripts of Visual-B from P3
6.4.3 **Comparison of the similarity between Visuals A and B**

Table 6.14 demonstrates the understandings and/or interpretations toward the messages embedded in Visuals A and B amongst 5 participants who took part in the initial and main eye-tracking test. The data was drawn from the protocol transcripts. All 5 respondents (3 with full records of visual recordings and analyses, and protocol transcripts; 2 with only raw visual sources and protocol transcripts) identified that both Visuals A and B were about the design or making of something. They also agreed that both visuals provided almost precise information and almost accurate details, which could assist the making or building of that something. The only different was one with some measurements; and the other was without any given dimension. Therefore, both representations matched the KEP-3: PRECISION of data to communicate ACCURACY or TRUTH.

<table>
<thead>
<tr>
<th>Participant (P)</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Both are informative illustrations, explaining how things work; how things are put together (28 sec).</td>
</tr>
<tr>
<td>P2</td>
<td>Both are for assembly of products; provide details and criteria (56 sec).</td>
</tr>
<tr>
<td>P3</td>
<td>Both communicate through diagrams, which illustrate forms and how to build an object; and how the object would work; provide different views/sections about the objects; show the purpose; show the dynamic and function; ultimately, about how to build and the design of product (112 sec).</td>
</tr>
<tr>
<td>P4</td>
<td>Both are visuals to make us see the truth of making something 1) kites and 2) a mechanism to carry weight; Both provide details that 1) with theory, details and measurements and 2) precise visual details on how it works just without measurements (46 sec).</td>
</tr>
<tr>
<td>P5</td>
<td>Both tell us how to make something; giving lots of details on how they work (48 sec).</td>
</tr>
</tbody>
</table>

Table 6.14

Verbal Protocol for the Comparison of Visuals A and B of 5 Participants
6.5 Results of Validation Study

A similar method to analysing Visuals A and B in terms of transferring the video clips into snapshot frames was applied to obtain reading and understanding patterns for Visuals C and D (Pair-1) for this validation study. These representations of the scanpaths were then analysed in parallel with the respondents’ protocol transcripts. The time spent in understanding the visual messages and the prompted questions are also shown together with the analysis in Table 6.15.

6.5.1 Results of Pair-1: Visuals C and D and their links to KEPs of VCT

The in-depth visual analysis being reported in this section covers the first pair of visual representations (one from the current practice; another from the 16th Century example) of 3 participants. A similar and consistent pattern of the sequence of eye fixations between AOIs was shown amongst the 3 respondents. Table 6.16 displays the sequential patterns of their eyes’ fixations on certain AOI. This demonstrates the respondents’ actual reading patterns of visual information.

6.5.1.1 Pair-1: Journey and patterns of reading Visual-C

(analysed from Tables 6.16 and 6.17)

- All 3 respondents first fixed their eyes on the human figure (the boy), and then to the objects, initially those nearest and gradually moved outward. [NB: Production factory; car with the banner; disassembly tools; and recycle/reuse box are the four main AOIs that circled the boy on the skateboard. The further away AOI are raw materials and design buildings.]

- Two of them (P1 & P2) looked at the production factory right after fixing their eyes on the boy with the skateboard, following by scanning through the raw material and design buildings.

- One of them (P3) scanned through the disassembly tools and recycle/reuse box right after fixing their eyes on the boy with the skateboard, and then briefly fixed her eye on the car and production factory, and later scanned through the raw material and design buildings.
### Areas of Interest (AOI) with Protocol Transcripts

<table>
<thead>
<tr>
<th>Areas of Interest</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Participants' Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Human on Skateboard</strong></td>
<td><img src="image1" alt="Scanpath Frames" /></td>
<td>0-8</td>
<td><em>I see a boy on a skateboard and...</em></td>
</tr>
<tr>
<td><strong>2. Disassembly</strong></td>
<td><img src="image2" alt="Scanpath Frames" /></td>
<td>...</td>
<td><em>...another thing below him.</em></td>
</tr>
<tr>
<td><strong>3. Banner and Car</strong></td>
<td><img src="image3" alt="Scanpath Frames" /></td>
<td>9-25</td>
<td><em>Behind him is a car that is going quite fast, and another car, then there is a banner or finishing line with another skateboard indicated.</em></td>
</tr>
<tr>
<td><strong>4. Recycle/Reuse</strong></td>
<td><img src="image4" alt="Scanpath Frames" /></td>
<td>26-48</td>
<td><em>Oh, there is a recycling box, a representational cycle or recycle of some kind.</em></td>
</tr>
</tbody>
</table>

*Table 6.15 continues on next page...*
<table>
<thead>
<tr>
<th>Areas of Interest (AOI)</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Participants' Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Production</td>
<td><img src="image1" alt="Scanpath Frames" /></td>
<td><img src="image2" alt="Scanpath Frames" /></td>
<td>52-59 Ah...ok, so we have a factory, which has...</td>
</tr>
<tr>
<td>6. Raw Material</td>
<td><img src="image3" alt="Scanpath Frames" /></td>
<td><img src="image4" alt="Scanpath Frames" /></td>
<td>1:00-1:08 ... raw materials delivered to it.</td>
</tr>
<tr>
<td>7. Design</td>
<td><img src="image5" alt="Scanpath Frames" /></td>
<td><img src="image6" alt="Scanpath Frames" /></td>
<td>1:09-1:19 Right at the back of the road there is a design centre. I guess, what I am seeing is a journey of a product, but there are 2 products, a skateboard and a car.</td>
</tr>
</tbody>
</table>

Table 6.15 continues on next page...
### Areas of Interest (AOI)

<table>
<thead>
<tr>
<th>7. Design</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Participants' Responses</th>
</tr>
</thead>
</table>
|           |                 | **P1.2:** What are the main stages of the life cycle of a product? | 29 | *It is about product design,...*  
|           |                 |             |                         |  
|           |                 | **P1.2:** What are the main stages of the life cycle of a product? |             | *...then is manufactured for more materials, which shows consumer resources like fuels, produces a mission, the products were then used and during its useful life,...*  
|           |                 |             |                         | *...disassemble and recycle.*  
|           |                 | **P1.3:** What are some of the key strategies to improve the environmental performance? | 14 | *Fuels efficiency, also the materials that can be reuse and where they sourced from.*  

| Table 6.15 |  
| Sample Analysis of Scanpaths, AOI and Protocol Transcripts of Visual-C from P3 |
Findings: Sequence of Eye Fixations on AOI

### VISUAL/AOI

**Area Of Interest (AOI)**
- Design
- Raw Materials
- Production
- Banner & Cap
- Human On Skateboard
- Recycle/Reuse
- Disassembly

**Timeline**

### AOI Sequence & Frequency Chart

#### Participant 1 (P1)

<table>
<thead>
<tr>
<th>Visual-C</th>
<th>Without Prompts (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual-D</td>
<td>Without Prompts (P)</td>
</tr>
</tbody>
</table>

Table 6.16

Pair 1: P1’s Eye-tracking Sequence Chart
Findings: **Sequence of Eye Fixations on AOI**

### Table 6.17

**Pair 1: P2’s and P3’s Eye-tracking Sequence Chart**

<table>
<thead>
<tr>
<th>VISUAL/AOI</th>
<th>AOI Sequence &amp; Frequency Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>P2</strong></td>
</tr>
<tr>
<td><img src="image" alt="Visual-C" /></td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td><strong>Area Of Interest (AOI):</strong></td>
<td>Without Prompts</td>
</tr>
<tr>
<td>Design</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Raw Materials</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Production</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Banner &amp; Car</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Human On Skateboard</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Recycle/Reuse</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
<tr>
<td>Disassembly</td>
<td><img src="image" alt="Timeline" /></td>
</tr>
</tbody>
</table>

| ![Visual-D](image) | ![Timeline](image) | ![Timeline](image) |
| **Area Of Interest (AOI):** | Without Prompts | P2 1 | P2 2 | P2 3 | P2 4 |
| Pulley’s Handle | ![Timeline](image)          | ![Timeline](image)          |
| Pulley/Lever/Blade/Pedal | ![Timeline](image) | ![Timeline](image) |
| Wood On Conveyor Belt | ![Timeline](image) | ![Timeline](image) |
| Wheel/Pedals | ![Timeline](image)          | ![Timeline](image)          |
| Operator (Human) | ![Timeline](image)          | ![Timeline](image)          |

Table 6.17

Pair 1: P2’s and P3’s Eye-tracking Sequence Chart
• All 3 respondents showed significant patterns of repeatedly looking back at the boy on the skateboard and the car with a banner when they recognised that the poster is about the life cycle of 2 products (revealed in respondents’ protocol transcripts, and the analysis shown in Tables 6.15 to 6.17). [NB: They were able to identify that the poster is about 2 products: the boy’s skateboard and the car behind the boy.]

• The scanpaths sequence chart (Tables 6.16 and 6.17) depicts that the ‘Human on Skateboard’ and ‘Banner and Car’ were the most frequent AOI that all participants looked back and made reference to. [NB: This pattern suggests that the viewers were trying to make connections between the 2 main characters of the poster, and subsequently they were referring to other AOI/objects around these 2 in order to find further obvious or hidden messages.]

6.5.1.2 Pair-1: Journey and patterns of reading Visual-D
(analysed from Tables 6.16 and 6.17)

• The starting point of fixations on the AOI for all 3 participants was slightly different in Visual-D. However, all 3 of them recognised that the key visual elements of this illustration are about the machine and its operation. Thus, they either looked first at the machine or the human figure (the operator). [NB: The main visual elements of this illustration are the machine and the operator; however, the researcher divided the AOI based on several key devices of the machine for tracking details of the studied visual.]

• P1 began the eye fixation on the AOI of ‘Wheel and Pedal’ (the operator’s foot is on the pedal of the machine’s wheel); P2 started with the AOI of ‘Operator/Human’; and P3 looked at the ‘Pulley/Levers/Blade/Pendulum’ as the first AOI (the operator’s hand is pulling the handle that links to the pulley which operates the levers, blade and pendulum). [NB: Although the participants did not start at the same point of the detailed AOI, they did show similar patterns of making comparison and connections to those
shown for Visual-A. The scanpaths showed them looking for links between the human and objects (parts of the machine). Initially those AOI nearest to the human were scanned and then the participants gradually moved outwards, as the device parts they looked at first were those connected to either the operator’s hand or foot.]

• The AOI of ‘Operator’ and ‘Pulley/Levers/Blade/Pendulum’ were the most frequent AOI that all participants looked back and made reference to (sequence chart of Visual-D, Table 6.16), second frequent AOI was ‘Wheel and Pedal’. [NB: These AOI are immediately linked to the operator.]

6.5.1.3 Pair-1: Comparison of the similarity between Visuals C and D

• The interpretation at this section is based on Tables 6.18 to 6.20. Tables 6.18 and 6.19 illustrate the messages perceived by the 3 participants, either from what they have understood or interpreted in relation to the AOI from their scanpaths. Table 6.20 shows the five participants’ understanding or interpretation of the messages with the time of the descriptions within the protocol. The data was drawn from the protocol transcripts.

• All 5 respondents (3 with full records of visual recordings and analyses, and protocol transcripts; 2 with only raw visual sources and protocol transcripts) agreed that both visuals tell the story of product(s) and their associated technologies or processes (Table 6.20). Three of them (non-engineering background) emphasised that both visuals use human depictions as a reference to provide messages about the product(s) depicted, e.g. reference to some sort of dimensions, processes involved and/or functions of the products in relation to the environment or technology around them (Tables 6.18 – 6.20). Overall, the representations were reported as providing perspectives of messages or stories relating to the content of the visual information; where the human becomes the centre point for the readers to connect and explore relationships to the surrounding AOIs. Thus, the human figure provides a starting or reference point for the readers.
<table>
<thead>
<tr>
<th>No.</th>
<th>AOI</th>
<th>Understood/Interpreted Message</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Participant 1 (P1)</td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td>All 3 participants pointed out that they were 1st looking at the person/boy and recognised that he was on a skateboard.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participants 1 and 3 recognised the skateboard as one of the product designs described; linked its longer life cycle compared to the car (when linked to AOI 'Car'); and it is better for the environment during use and later for recycling (linked to AOI 'Recycle/Reuse').</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>All 3 participants recognised this AOI as a production place; where all the raw materials, disassembly and recycle/reuse of the materials took place (when linked to AOI 'Raw Materials'; 'Disassembly'; 'Recycle/Reuse').</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All 3 participants linked these AOs to the design and production of better resources for the products' useful lives or their life cycles.</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>Participants 1 and 3 recognised this AOI as a design centre/school.</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>All 3 participants recognised that the 2 main AOs provide the message about the life cycle of the 2 products; and renewable/reusable materials (when linked to the AOI 'Raw Materials').</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.18
Sequence of Key Connections in the Scanpaths for Visual-C of 3 Participants
<table>
<thead>
<tr>
<th>No.</th>
<th>AOI</th>
<th>Understood/Interpreted Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>All 3 participants comprehended that the operator (human) is pulling something to operate the machine, and then pushing the wheel with his leg to move the wood on the conveyor belt.</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>All 3 participants recognised that these 3 AOIs are the basic elements/tools for the machine.</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>All 3 participants recognised that the elements/tools at this AOI would be moving up-and-down when the operator pulled the handle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant-3 recognised this AOI contained a saw to cut the wood when it moves up-and-down.</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>All 3 participants were comparing the human and the whole machine while being asked what needed to be considered if they were to build the machine. They were agreed on what the size of the machine must be in relation to the size of the human.</td>
</tr>
</tbody>
</table>

Table 6.19
Sequence of Key Connections in the Scanpaths for Visual-D of 3 Participants
Pair-1 Visuals

<table>
<thead>
<tr>
<th>Current Visual Tools</th>
<th>16th Century Visual Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Current Visual" /></td>
<td><img src="image2" alt="16th Century Visual" /></td>
</tr>
</tbody>
</table>

Responses

<table>
<thead>
<tr>
<th>Participant (P)</th>
<th>Both have human; both shown via 3D drawing; both tell a story or action about process and function or operation (60 sec).</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>Both show technology in time 1) with high-tech and 2) manual-tech (65 sec).</td>
</tr>
<tr>
<td>P3</td>
<td>Both are diagrammatic representations, employed perspective; both use human figures to demonstrate the proportions; giving a perspective of the content (100 sec).</td>
</tr>
<tr>
<td>P4</td>
<td>Both show the process of producing something or showing a physical transformation of something (28 sec).</td>
</tr>
<tr>
<td>P5</td>
<td>Both are diagrammatic drawings that have humans involved, showing some hand-on and describing an overall process (66 sec).</td>
</tr>
</tbody>
</table>

Table 6.20
Verbal Protocol for the Comparison of Pair-1 Visuals of 5 Participants
6.5.1.4 **Key findings and links to KEPs of VCT**

- Although visuals C and D were produced more than 400 years apart, they possessed a similar approach of having a human figure in the visual representation, intentionally providing extra messages or relationships.

- The journeys and patterns of reading visuals C and D were almost consistence throughout 5 respondents.

- All 5 respondents demonstrated repeatedly referring back to the ‘human figures’ (most frequently revisited AOI) in both visuals C and D. The human figure, as the central focus, was used as a benchmark in reference to other objects surrounding it for the purpose of ‘comparing’ and making ‘connections’, so finding possible ‘relationships’ in within, and hence to encode the story or messages embedded in the visual representations (evidence in sections 6.5.1.1 until 6.5.1.3 and Table 6.20). This key eye and mind actions were as anticipated and intended by the KEP-1 (COMPARE to reveal CONNECTION and RELATIONSHIP) in technical visual information.

* NB: The analysis results shown in Tables 6.15 is only a samples results from one of the respondents, the complete results for all participants can be found in Annexes attached as in the form of DVD.
6.5.2 Results of Pair-2: Visuals E and F and their links to KEPs of VCT

A similar method of analysing Visuals C and D was applied to obtain reading and understanding patterns for Visuals E and F. However, during the analysing process, it was found that the crucial thing for this case study was not about the sequence of reading images or which AOIs were most important. Instead, it was of more concern in regards to whether the eye-tracking could trace the application of KEPs, and whether this aspect of KEPs helped the readers comprehend the visual information.

Therefore, the report in this section straightaway focuses into the key elements that make the visual information understood which directly relates to the KEPs applied, rather than reporting the whole journey and patterns of readings. This strategy was the same as those applied in analysing Visuals A and B for the earlier main study of the kite-VTI and da Vinci’s drawing. The report details include capturing the eye scanning paths, not in a continuous sequence of the whole journey, but directly corresponding to the participants’ protocol transcripts in a particular understanding of key messages which related to the KEPs. For the complete analysis results of the overall journey for all participants, this can be found in Annexes attached in DVD.

6.5.2.1 Results of Visual-E and its links to KEPs of VCT

Table 6.12 displays the patterns of eyes’ scanning paths and their descriptions on how they understood the messages on Visual-E by 3 participants.

- All 3 participants were able to use the colours scheme to judge whether an aspect was good or bad.
- All 3 of them recognised the web helps to plot different aspects of ecological criteria, allowing them to consider these during their designing processes.

These 2 aspects showed that the readers were able to use the visual form to make further considerations or decisions towards their design practices. This means that the visual representation was successfully achieved the intention of its form and it was functional, as stated in KEP-2: unity of FORM to accentuate FUNCTION.
### Prompts (P):

3.1 What is the purpose of this diagram?
3.2 How does the colour scheme work?
3.3 If you were asked to aim for “reuse, reduce and recycle”, what does the diagram suggest you could do?
3.4 How could you use this tool to improve your designing (from an ecodesign perspective)?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1.png" alt="Scanpath Frame 1" /></td>
<td>3.1 What is the purpose of this diagram?</td>
<td>The colour legend helps.</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2.png" alt="Scanpath Frame 2" /></td>
<td>3.2 How does the colour scheme work?</td>
<td>The lines linking at each stage provides very good guide for detailed information.</td>
</tr>
<tr>
<td>3.</td>
<td><img src="image3.png" alt="Scanpath Frame 3" /></td>
<td>3.3 If you were asked to aim for “reuse, reduce and recycle”, what does the diagram suggest you could do?</td>
<td>The bigger web is a better design solution.</td>
</tr>
<tr>
<td>4.</td>
<td><img src="image4.png" alt="Scanpath Frame 4" /></td>
<td>3.4 How could you use this tool to improve your designing (from an ecodesign perspective)?</td>
<td>Ecodesign web is a diagram or tool to show you how to analyse how eco-friendly in product design.</td>
</tr>
</tbody>
</table>

Table 6.21
Scanpaths and Protocol Transcripts of Visual-E from P1
<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td><strong>P3.2</strong> How does the colour scheme work?</td>
<td>The colours are providing scale from bad (in the centre with red) to good (in green).</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td><strong>P3.4</strong> How could you use this tool to improve your designing (from an ecodesign perspective)?</td>
<td>The web allows us to consider different factors. We can increase the scales that we want in any element selected. It helps to steel our directions for design.</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td>It is a kind of mind map of a few different kinds of specifications, starting from the top is the new ways of doing things.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Across are materials selection, material usage, distributions, product use, optimum life and end of life.</td>
</tr>
</tbody>
</table>

Table 6.22
Scanpaths and Protocol Transcripts of Visual-E from P2
### Prompts (P):

- **3.1** What is the purpose of this diagram?
- **3.2** How does the colour scheme work?
- **3.3** If you were asked to aim for “reuse, reduce and recycle”, what does the diagram suggest you could do?
- **3.4** How could you use this tool to improve your designing (from an ecodesign perspective)?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1" alt="Scanpath Frame" /></td>
<td><strong>3.1</strong> What is the purpose of this diagram?</td>
<td><strong>Eco design web is used to measure and to analyse the relative ecological value of the design in terms of seven different practices.</strong></td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2" alt="Scanpath Frame" /></td>
<td><strong>3.2</strong> How does the colour scheme work?</td>
<td><strong>The colour red signified bad, green is good.</strong></td>
</tr>
<tr>
<td>3.</td>
<td><img src="image3" alt="Scanpath Frame" /></td>
<td><strong>3.3</strong> If you were asked to aim for “reuse, reduce and recycle”, what does the diagram suggest you could do?</td>
<td><strong>P3.4 How could you use this tool to improve your designing (from an ecodesign perspective)?</strong></td>
</tr>
<tr>
<td></td>
<td><img src="image4" alt="Scanpath Frame" /></td>
<td><strong>3.4</strong> How could you use this tool to improve your designing (from an ecodesign perspective)?</td>
<td><strong>The size of the enclosed area in the centre of web denotes how ecological the design is overall, and also the shape helps us to see which aspects could be improved most originally.</strong></td>
</tr>
</tbody>
</table>

Table 6.23
Scanpaths and Protocol Transcripts of Visual-E from P3
Additionally, the repetitions of reading from a visual element to another, shown by all 3 participants, were also matched the KEP-1 of the VCT principles. This natural reaction of eye movements of reading visual were about ‘comparing’ and making ‘connections’ and ‘relationships’ in order to make sense of meanings and decode messages. This aspect can be observed from the eye movements’ sequential chart of the 3 participants, which were quite similar when reading Visual-E (Table 6.24).
6.5.2.2 Results of Visual-F and its links to KEPs of VCT

Tables 6.25 to 6.27 display the patterns of eyes’ scanning paths and their descriptions on how they understood the messages on Visual-F by 3 participants.

- All 3 participants were able to identify Visual-F as a type of diagrams which has 3 matrices that helps to find some equations (in this case, it was to calculate the BHP).

- All 3 of them could answer the questions correctly in regards to the equations by only using the visual diagram, although P2 had taken a slightly longer time to figure out how to read the matrix.

These 2 aspects showed that the readers were able to use the visual matrix to integrate and find the engine size (BHP). This means that the visual representation successfully achieved the intention of its form of being a functional as a visual calculator. The form and the functional aspects of the visual matrix were depicted as stated in KEP-2: unity of FORM to accentuate FUNCTION.
Prompts (P):
4.1 What is the purpose of this diagram?
4.2 When the r.p.m = 4,000 and torque = 400 units, what is the brake horsepower (BHP) of the engine?
4.3 If the r.p.m stays the same, what could happen to the torque and BHP?
4.4 If you were to design a less powerful engine, what could happen to the r.p.m, and torque?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><img src="image1.png" alt="Scanpath 1" /></td>
<td><strong>P4.2</strong> When the r.p.m = 3,000 and torque = 300 units, what is the horsepower of a brake engine (BHP)?</td>
<td>The BHP is about 200.</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2.png" alt="Scanpath 2" /></td>
<td><strong>P4.2</strong> When the r.p.m = 3,000 and torque = 300 units, what is the horsepower of a brake engine (BHP)?</td>
<td>The BHP is about 200.</td>
</tr>
<tr>
<td>No.</td>
<td>Scanpath Frames</td>
<td>Prompts (P)</td>
<td>Descriptions</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------</td>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td><img src="image1" alt="Image" /></td>
<td><strong>P4.1</strong> What is the purpose of this diagram?</td>
<td>A schematic drawing that help to find BHP, and it provides an equation.</td>
</tr>
<tr>
<td>2.</td>
<td><img src="image2" alt="Image" /></td>
<td><strong>P4.2</strong> When the r.p.m = 4,000 and torque = 400 units, what is the horsepower of a brake engine (BHP)?</td>
<td>The BHP is about 200.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Initially P2 was unable to answer, but with some hints and a longer time spent on the nomogram, P2 could answer at the end.)</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td><img src="image3" alt="Image" /></td>
<td><strong>P4.3</strong> If the r.p.m stays the same, what could happen to the torque and BHP?</td>
<td>Torque would be reduced; and BHP would also have gone down.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>P4.4</strong> If you were to design a less powerful engine, what could happen to the r.p.m, and torque?</td>
<td>When BHP is less power, torque and speed are low as well.</td>
</tr>
</tbody>
</table>

Table 6.26
Scanpaths and Protocol Transcripts of Visual-F from P2
**Prompts (P):**

1. What is the purpose of this diagram?
2. When the r.p.m = 4,000 and torque = 400 units, what is the brake horsepower (BHP) of the engine?
3. If the r.p.m stays the same, what could happen to the torque and BHP?
4. If you were to design a less powerful engine, what could happen to the r.p.m, and torque?

<table>
<thead>
<tr>
<th>No.</th>
<th>Scanpath Frames</th>
<th>Prompts (P)</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>P4.1</td>
<td>What is the purpose of this diagram?</td>
<td>A graphical diagram to consider speed and torque in relation to BHP and the use to consider the efficiency of the engine brake and energy usage.</td>
</tr>
<tr>
<td>2.</td>
<td>P4.2</td>
<td>When the r.p.m = 4,000 and torque = 400 units, what is the horsepower of a brake engine (BHP)?</td>
<td>The BHP is about 300.</td>
</tr>
</tbody>
</table>
| 3.  | P4.3            | If the r.p.m stays the same, what could happen to the torque and BHP? | If the Torque was 200; then the BHP would be about 250; or When the Torque was a 100; the BHP should be under 80.  
   *It’s understood that the faster the engine, the lower the BHP is.* |
6.5.2.3 Pair-2: Comparison of the similarity between Visuals E and F

Table 6.28 demonstrates the understandings and/or interpretations of all 5 participants toward the messages embedded in Visuals E and F. Time spent in providing the descriptions also indicated within the protocol. The data was drawn from the protocol transcripts.

- All 5 respondents (3 with full records of visual recordings and analyses, and protocol transcripts; 2 with only raw visual sources and protocol transcripts) identified that both Visuals E and F were a type of matrix. They also identified that both visuals matrices could provide almost precise information and/or accurate scales, only one is by language descriptions together with colours scheme; and the other is using numbering scheme.
- Overall, the representations were treated as a visual form that functioned to plot tertiary information; and hence they matched the intention of the KEP-2: Unity of FORM to accentuate FUNCTION (evidence can be traced back in sections 6.5.2.1 and 6.5.2.2, Tables 6.21 to 6.23, 6.25 to 6.27 and 6.28).
**Table 6.28**  
Verbal Protocol for the Comparison of Pair-2 Visuals of 5 Participants
6.6 Reliability and Validity of the Case Study Results

The reliability of the results found in Case Study-2 was verified via the triangulation as demonstrated in Figure 6.8. The first data collection was through the survey of literature, where the KEPs of VCT had emerged. The second source of data was collected from the kite-VTIs design and redesign. They were tested through Case-Study-1 (as visual information sources for the students’ kite-designing workshop). The third form of data was attained from the eye-tracking on the reading patterns. Evidence that the KEPs help in better assisting visual reading was obtained.

To further validate the triangulation findings, another round of data collection was obtained from the KEPs validation. This was done using eye-tracking analysis of the 16th Century and current visuals. These visuals had been identified as being effective in their actual practice.
The findings of the kite-VTI design, as well as the analysis of the 16th Century and other current visuals showed significant patterns and use of the KEPs of VCT. Hence, a further more in-depth study and articulation of the KEPs within a richer context seemed appropriate to be carried out for the overall validity of the whole research case. Therefore, Case Study-3 was plotted to provide another perspective of corroborations evidence and validation.

### 6.7 Summary of Key Findings

Table 6.29 summarises the key findings from the Case Study-2:

<table>
<thead>
<tr>
<th>Key Studies in Case Study-2</th>
<th>Validation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Kite-Poster Design</td>
<td>Validation: 16th Cen. Vs. Current Practice</td>
</tr>
<tr>
<td>(2) Eye-Tracking on Kite-Poster</td>
<td></td>
</tr>
</tbody>
</table>

#### Key Findings

1. **KEPs-1, -2 and -3** could be tracked by the participants’ reading patterns (eye-scanning paths which were traced by the eye-tracker device) on the visuals (sections 6.4.1 and 6.4.2; Tables 6.10 to 6.13).

   - The validation study had also confirmed that:
     1. The selected 16th Century visuals and those selected visuals in current practice shared similar qualities of KEPs.

2. The understanding of the visuals, where the participants described the visual depictions and answered correctly the prompted questions, could as well identify the application of the KEPs (questionnaire survey findings of the kite-posters from Case Study-1; Chapter 4: the intention of the design and redesign; and sections 6.3 to 6.4).

   - 2. The applied KEPs-1, -2 and -3 were traced through eye-scanning paths, as well as via the descriptions by the participants.

These can be referred to the results in sections 6.5.1 and 6.5.2.
Chapter 7  Case Study-3  
[VCT and KEPs in Context]

Chapter Overview

Chapter Seven describes how the third case study that had been designed to explore the VCT and its KEPs within a complex educational context was conducted. It explains how the case study was carried out and the results obtained. Case study design, selections of visuals and data collection methodologies are described, whilst the collected data is interpreted and reported. The associated issues concerning reliability and validity are also discussed. Figure 7.1 illustrates how Chapter Seven fits into the structure of this thesis.
7.1 Case Study-3 Design

The third case study was designed to attain further validity for the VCT and its KEPs through comparison with the previous two case studies. It was especially intended to investigate the impact of the KEPs for creating and reading images, and their further study and articulation in a richer setting within the context of materials technology. The set-up of the Case Study-3 using the context of materials technology rather than other possible technologies was based on the following rationale.

7.1.1 The role of materials technology in ID and ED

Materials technology plays an essential role in industrial and engineering design (as mentioned in section 2.3.2 and 2.3.3, Chapter 2). In addition, Ashby and Johnson (2004, p. 35) also indicated that a product’s aesthetics, associations and perceptions are intensely influenced by the choice of the materials and its processing, so to instil the product with a personality that reflects the material itself. Materials and its technology, in this sense, play a central role in allowing integration between technical design (ED aspect) to meet functionality requirements and imaginative industrial design (ID concern) for proper consideration of the user’s aesthetic and emotional needs in the design of a product (Ashby and Johnson 2003, p. 35).

7.1.2 Contemporary product design and current education and research for materials technology

There has recently been an increasing interest focus amongst designers and users in searching for hedonic or expressive feel in contemporary product design, not only just its functionality alone. In current sophisticated market places of developed nations, to purchase a product, consumers commonly seek satisfaction for their aesthetic and emotional needs. These facts were also implied by many other educators and researchers in this area, e.g. Ashby and Johnson (2003); Karana (2010); Pedgley (2010); and van Kesteren (2010).
Education and research in this context seems to be changing from placing its main emphasis on engineering aspects to a more balanced approach between technical and sensorial properties. Examples can be seen from scholarly papers related to materials technology from Special Files in Journal of the Faculty of Architecture, METU 2010.

7.1.3 **Changes of visual representation in materials resources**

Subsequent to these shifts in emphasis, the visual tools used in representing and approaching the context also seem to have moved from typically ‘technical and linear’ diagrams to more complex representations.

For these reasons, this rich context of the education in materials technology for designers was selected for further verification concerning the validity of the KEPs and to complete the macro triangulation for the whole research study.
7.2 Data Collection Methodology

The VCT-in-context case study had four planned phases as shown in Figure 7.2.

- **PHASE-1**: Analysis of books on materials technology for ID and ED students
- **PHASE-2**: Analyses and redesigns of VTI
- **PHASE-3**: VTI Questionnaire Survey
- **PHASE-4**: Experts Discussion (Validation)

- Present results from Phase-1 and Phase-3.
- Discuss the results relating to KEPs of VCT.
- Gather the materials experts’ perceptions toward the results and possible expectations.
- The outcome will be used to validate the overall findings in Case Study-3.
7.2.1 **PHASE-1: Analysis of books on materials technology for ID and ED students**

This study was to compare and analyse the representations of technological information used in two well-known materials design books. One was by Ashby (2005) intended for the ED students (Figure 7.3); and the other book was by Ashby and Johnson (2004), where the VCT used in the book was redesigned to suit the ID students (Figure 7.4). The analysis was intended to explore differences in the visual communication (VC) strategy adopted for the ED and ID students.

The selection of these 2 books is based on some commonality and differences between them. Both books have common elements of materials design and processes, materials selection, and materials properties etc. In addition, both books are written by the same author, Mike Ashby, who is an expert in materials and is a Professor in the Engineering Department at Cambridge University and a Visiting Professor at the Royal College of Art in London.
The second book was a collaborative effort with Kara Johnson, who works for IDEO (an international design consultancy) and is an expert in materials. Her work concerns supporting designers in the selection of materials and introducing unique methods of integrating materials in the design process. This collaboration intentionally changed the visual communication of the second book, especially emphasised on its representations. The authors hoped that these changes could serve as inspiring elements for creativity in designing. It is claimed by Ashby and Johnson (2004, p. 31) that, “the power of the visual image lies in the ease with which it can be manipulated by the mind and its ability to trigger creative thought.” Thus, these 2 books provide an opportunity in their different visual representations for comparing and contrasting their ID and ED intentions.

The visual representations from the books were analysed and evaluated through four observation lenses (Figure 7.5). These observation lenses were developed to be appropriate for use as the framework for this case study in tracking the application of VCT. The lenses allowed different perspectives of VC and graphical strategies, principles and techniques to be analysed. The strategy began with three ‘found’ lenses that comprised:

1. **Types of Models** (based on Baynes, 2009 – the nature of model)
2. **Graphical Strategies** (based on Danos, 2009 – graphicacy categories)

The lenses were used to articulate the principles applied in good VCT practice. A literature review was conducted for each area of concern, but with the focus on graphical application as this is the key area of the research.

The 4th lens: **Key Emerging Principles of VCT** came from the analysis of a literature review (Beh and Norman, 2009), which was undertaken to explore the validity of good practice in VCT.
However, this lens-4 was only used to examine 4 selected visuals (shown in the case study results section), 2 from the ED book and 2 from the ID book.

![Diagram](image.png)

**Figure 7.5**
Observation Lenses for the Analysis of VCT of the 2 Materials Books

### 7.2.2 PHASE-2: VTIs Analyses and Redesigns

A total of 7 examples of visual-technological-information (VTI), mainly diagrams, illustrations and graphs, from books and scholarly papers were selected for this phase of study. The sources of selection can be found in section 4.3, Chapter 4.

The analysis of the selected representations was focused on their use of forms, layouts and detailed visual elements and/or annotation applied in them. These foci were the key aspects to determine the effectiveness of communication, particularly, in delivering their messages by the depicted images and/or even a line (a form of graphic). The established KEPs were used as guidelines to assess and analyse the strengths and weaknesses of the selected representations. Subsequently, redesigned versions were developed to strengthen the weaker aspects that had been identified (detailed analyses and illustrated redesigns can be found in section 4.3, Chapter 4).
7.2.3 **PHASE-3: Questionnaire Survey**

Out of the seven VTIs from the phase-2 analyses and redesigns, five were selected for further investigation through a questionnaire survey. An example of the question structure used based on a comparison of the original and redesigned VTIs is as shown in Figure 7.6 (the remainder of the questions used a similar format; the entire set of questionnaire is in Appendix 7.1). The structure of the questionnaires was based on the following foci:

- Understanding of the messages carried in the diagram
- Value of the diagram for the design practice
- Judgement of effective visual representation
- Features that catch the attention
- Features that made understand the message
- Additional comments (if have any)

An introductory PowerPoint slide presentation (Appendix 7.2) regarding a brief to the VTIs questionnaires and some ideas about the research intention were presented to those students, who had the voluntary basis to choose whether to answer the questionnaire.

Overall, it was intended to gather data concerning reading preferences, perceptions and interpretation of visual information within the context of materials technology.

Some personal/background details were asked for in the research questionnaire such as the respondents’ name and email address (both optional), academic background/prior knowledge, cultural background, age and gender groups. This was data that would be analysed as part of the research as it was considered that these factors may have some influence on the findings. Respondents would be anonymous in all published outcomes (as to comply with the Loughborough University’s ethical guidelines).
2. By comparing the visual representations above, answer the following questions from 2.1 until 2.6:

2.1 What is the key message that the visuals H and I imply?

........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

2.2 How valuable is the message in 2.1 to your designing? (√ one only)

Not Important  Some Importance  Important  Very Important

2.3 By comparing visuals H and I, which one do you find is more effective in conveying its message? (√ one only)

Visual H  Visual I

2.4 Which features catch your attention in the visual of your choice in 2.3? (Please state them in order if possible)

........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

2.5 Which features of the visual of your choice in 2.3 or 2.4 are key to enabling your understanding?

........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

2.6 Do you have any other comment on these visuals?

........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

Figure 7.6
Sample of the Structure of the Materials Diagram Questionnaires
(Image H: Material Languages cited in Pedgley 2010, p. 347)
7.2.4 **PHASE-4: Discussion with Materials Experts**

The results from the 3 earlier phases of this Case Study-3 (book analysis; VTIs analysis and redesign; and VTIs questionnaire survey) were presented to materials experts in order to validate the results through discussion. A PowerPoint slice presentation (shown in Appendix 7.3) was used to display the VTIs and the key findings throughout the discussion session.

The materials experts were from 3 different higher institutions in 3 countries from 3 different regions. They were selected based on their expertise, which included: Materials Engineering, 1 from Loughborough University (LU); and 1 from Politeknik Ibrahim Sultan (PiS); and 1 from Materials in Industrial Design, Middle East Technical University (METU). They were also selected because they are the lecturers for the students in the survey samples (detailed in section 7.2.5). They are considered as experts due to their professional academic background and educational practice as follows:

**Expert-A (LU)** is a Senior Lecturer and Programme Director for Design with Engineering Materials at LU. He attained a B. Eng and M. Phil in China, and D. Phil in Oxford University from the Department of Materials. He started his higher education career in Tianjin University, China as an Assistant Professor, Lecturer, then to Associated Professor and Professor. He became the Director of the Key Laboratory of Advanced Ceramics and Machining Techniques, funded by the Ministry of Education in China. He then spent a year undertaking a Sino-British Friendship Fellowship, which was followed by 4 more years as a Research Fellow in Oxford. He is a Senior Lecturer at LU, after a similar post at Coventry University (Wu, 2012).

**Expert-B (PiS)** is a Senior Lecturer in the Mechanical Engineering Department, PiS. He attained BSc and MEd in Materials Engineering. His educational practice includes: Strength of Materials and Materials Technology.
Expert-C (METU) is an Associated Professor in the Department of Industrial Design, METU. He attained a BSc in Industrial Design & Technology and PhD Industrial Design from LU. His current research interests are in the areas of materials and manufacturing for industrial design, user-product experiences, and research through design(ing). His educational practice includes: Manufacturing Materials, Industrial Design, and Design Research for Interaction, Materials Experience (Pedgley, 2012).

The foci of the discussion with materials experts were mainly built from the key findings from the ID versus ED books analysis and the VTIs questionnaire survey. A summary of the results were as shown in Figure 7.7.

<table>
<thead>
<tr>
<th>ID vs. ED Books Analysis</th>
<th>VTIs Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different types of representational models used</td>
<td>Redesigned VTIs were more effective visually to get attention and communicating the messages.</td>
</tr>
<tr>
<td>Different graphical strategies used</td>
<td>No difference of understanding and visual effectiveness in VTIs between ID and ED students, or for cultural background.</td>
</tr>
<tr>
<td>Similar graphical techniques applied</td>
<td>Some evidence of educational level affecting understanding and visual effectiveness.</td>
</tr>
<tr>
<td>Similar KEPs of VCT applied, but not completely successful</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.7
Summary of the Key Findings from ID vs. ED Books Analysis and VTIs Questionnaire

The foci of the discussion were:

- Whether ID and ED students need different styles of VTIs to understand information concerning materials.
- Whether the results obtained from the 3 earlier phases of the study were as expected.
Their views regarding cultural differences (i.e. differences due to countries and educational backgrounds) in relation to understanding of the VTIs.

7.2.5 Sampling

There were a numbers of student-groups from different countries of different regions who participated in the questionnaire survey. They included students from:

1. Politeknik Ibrahim Sultan (PiS), Malaysia;
2. Loughborough Design School (LDS), UK; and
3. Middle East Technical University (METU), Turkey

These groups of students could be considered as a purposive sample in that they represented students in particular categories, which were either ID or ED. The ID and ED students from PiS could also be described as a convenience sample as they are a captive audience of students.

Whereas, the ID and BSc Product Design and Technology (to represent ED) students from LDS, and the ID group of METU were voluntary groups. They were introduced to the questionnaires and briefed regarding the research intention; however, answering the questionnaires was a voluntary activity. Due to this voluntary basis, 10 out of 30 ID, and 6 out of 26 ED LDS students; and all 12 ID METU students completed the questionnaires.

The BSc Product Design and Technology students from LDS were to represent an ED group based on the following rationale:

1. This BSc programme is accredited by the Institute of Engineering Designers (IED), whereby the students of this category can apply for the IED membership (IED, 2012).
2. The BSc students deal with technological aspects such as electronics and mechanics as compulsory subjects. These are considered to be very ED based aspects of designing (explained in section 2.3.2).
According to Myerson’s Report (1991), referring to Table 2.2, ID programmes require core technological content derived from such as Materials, Processes, Human Factors, Computing, Workshop Practice, and Manufacturing. ‘High-tech’ ID programmes, on the other hand, require the same technological content as mentioned for the ID core with additional content in areas such as Information Management, Engineering Science, Mechanical Engineering, and Electrical/Electronic Engineering. The boundaries between ID and ED programmes overlap somewhat in these technological areas and the BSc Product Design and Technology undergraduates are introduced to similar technologies to those that would be expected on an ED programme.

7.2.6 Piloting, issues and changes for Case Study-3

The first draft of the diagrams questionnaire was designed by putting all the seven redesigned diagrams. However, after testing the questionnaire, it took more than half an hour to be completed. This was thought to be too long to get volunteers to be involved. The second draft of questionnaire was revised and reduced to five diagrams questions, and each with six or seven detailed questions. The selected diagrams were chosen based on their complexity and richness of messages about materials technology. The questionnaire was then piloted again among three volunteers: 1 Materials Engineering undergraduate, 1 Mechanical Engineering PhD, and 1 Industrial Design PhD. The average time in completing the questionnaire was reduced to about 20 minutes, and was believed to be feasible for the actual survey. The question structure was also able to obtain data for the 5 aspects of the intended investigation. They were messages that the diagram carried; perceptions and judgements regarding value and effectiveness of visuals; features that catch the attention and made understood.
7.3 Results of Case Study-3

The results of this Case Study-3 will be reported in the following order:

- Results of the comparison and analyses between two books on technology for design students (ID and ED)
- Results of the analyses and redesigns of VTIs for materials technology
- Results of the expert discussion

7.3.1 Results of the comparison and analyses between 2 books on materials technology for design students (ID and ED)

This section reports the analysis using the 3 observation lenses for 2 selected chapters in these 2 books: the Introduction and Design Process chapters. However, the analyses for the rest of the chapters were focused by only the first lens, which was about the ‘types of models’. This was because it was found to reveal the most significant aspects amongst the 3 lenses, and was thought to be sufficient to report the representational models for the 2 books.

Before the in-depth lenses results reported, it would be appropriate to have an overview in terms of the general differences and similarity of the 2 books. In a general aspect of the comparison of the ED and ID books, particularly by comparing the overall books from a broad perspective and the application of the general VC, both books had different looks and feels, but applied similar good VC principles.

Examples of the differences in looks and feels were: the Introduction chapter of the ED book began with introducing evolution of materials through time (Figure 7.8) and in product: the vacuum cleaners (Figure 7.9). However, the ID book initiated an idea of science in new technologies (Figure 7.10), then highlighted the sustainability and environmental concerns (Figure 7.11) so as to reinforce and inform about the essential influencing factors for a product design.
The results of the lenses analyses showed significance differences of representational models (Lens-1) and graphicy strategies (Lens-2) applied in the VTIs of the 2 chapters for the 2 books.
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Lens-1: Types of Models

The overall presentation model and approaches of the visual representations used in the ED and ID books were very different, as clearly displayed in Table 7.1.

<table>
<thead>
<tr>
<th>Overall representation model of the book</th>
<th>One of the VTIs used in the book</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image of ED Book]</td>
<td>[Image of VTI from ED Book]</td>
</tr>
<tr>
<td>[Image of ID Book]</td>
<td>[Image of VTI from ID Book]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ED Book</th>
<th>ID Book</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall representation model of the book</td>
<td>Overall representation model of the book</td>
</tr>
</tbody>
</table>

Table 7.1

<table>
<thead>
<tr>
<th>Representational Models and VTIs used in the 2 Books of Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image of VTI from ED Book]</td>
</tr>
<tr>
<td>[Image of VTI from ID Book]</td>
</tr>
</tbody>
</table>

The linear Expansion Coefficient plotted against the Thermal Conductivity cited in Ashby, 2005, p. 67

Thermal Expansion Coefficient and Thermal Conductivity cited in Ashby and Johnson 2004, p.327
**Lens-1: on the *Introduction and Design Process* chapters**

The VTIs used in the 2 chapters of the ED book utilised many more ANALOGUE models as compared to very little use of ICONIC and SYMBOLIC models, as highlighted in Table 7.2. This was very different to the VTIs in the 2 chapters of the ID book, which used all types of models in a balanced manner to get the messages across, as noted in Table 7.3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>ICONIC</th>
<th>SYMBOLIC</th>
<th>ANALOGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction Chapter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Narrative-time chart</td>
<td></td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Product photograph/portrait</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>3</td>
<td>Comparison table</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td><strong>Design Process Chapter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Flowchart</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Class diagram</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>3</td>
<td>Collaboration diagram</td>
<td></td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

*Table 7.2 continues on next page...*
### Table 7.2
Analysis of the VTIs in ED Book, using Lens-1 *(Types of Models)*

<table>
<thead>
<tr>
<th>No.</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>ICONIC</th>
<th>SYMBOLIC</th>
<th>ANALOGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Activity diagram</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Context diagram</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>6</td>
<td>Interaction diagram</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>7</td>
<td>Drawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Diagrammatic drawing</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Product photograph/portrait</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Collaboration diagram</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>
## VTIs Used in ID Book

<table>
<thead>
<tr>
<th>No.</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>ICONIC</th>
<th>SYMBOLIC</th>
<th>ANALOGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction Chapter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Interaction sketch</td>
<td><img src="image" alt="Interaction sketch" /></td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cause-and-effect diagram</td>
<td><img src="image" alt="Cause-and-effect diagram" /></td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Package flowchart</td>
<td><img src="image" alt="Package flowchart" /></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>4</td>
<td>Sequential drawing diagram</td>
<td><img src="image" alt="Sequential drawing diagram" /></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>5</td>
<td>Product sketch and photograph/portrait</td>
<td><img src="image" alt="Product sketch and photograph/portrait" /></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Product photograph/portrait</td>
<td><img src="image" alt="Product photograph/portrait" /></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Product photograph/portrait</td>
<td><img src="image" alt="Product photograph/portrait" /></td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3 continues on next page...
### Chapter 7 Case Study - 3

#### VTIs Used in ID Book

<table>
<thead>
<tr>
<th>No.</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>ICONIC</th>
<th>SYMBOLIC</th>
<th>ANALOGUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Product photograph</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sketch/drawing diagram</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Various graphs and photograph</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Package flowchart table</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>5</td>
<td>Bubble diagram</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Detailed sketches</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Message photograph</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Product photograph/portrait</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>9</td>
<td>Relational table</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>10</td>
<td>Message graphic arts</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3 Analysis of the VTIs in ID Book, using Lens-1 (Types of Models)
An example interpretation of the VTIs analysis using Lens-1 (Types of Models)

Based on the results in Table 7.3 (Introduction chapter, item no. 4; an enlarged version: Figure 7.12), the individual element used in the diagram belongs to the ICONIC model as of its almost realistic representation drawing; however, the overall model of the diagram is SYMBOLIC because it proposes and symbolises a situation (an abstract code); yet, it informs a process of a flow diagram (indicated by arrows) to tell a story, and hence it is also an ANALOGUE model.

Figure 7.12
The Life of a Material cited in Ashby and Johnson, 2004, p. 11
Lens-1: on the overall representation models of the whole book for ID can be concluded as having majority of ICONIC model (approximately 72% of overall representations used this type of model); whereas, SYMBOLIC and ANALOGUE models are used at a very minimal level (about 15% for symbolic and 13% for analogue), as shown in Table 7.4. Conversely, the results for the types of models used were quite different from the ED book. For the ED book, about 60% of the VTIs are in the SYMBOLIC model category; the ICONIC category includes around 25% and the ANALOGUE category is only 15% of the overall visual representations (Table 7.5).

<table>
<thead>
<tr>
<th>Book's Chapters</th>
<th>Number of visuals used based on Baynes’s Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICONIC</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td><strong>Material Profiles</strong></td>
<td>47</td>
</tr>
<tr>
<td><strong>Shaping Profiles</strong></td>
<td>19</td>
</tr>
<tr>
<td><strong>Joining Profiles</strong></td>
<td>19</td>
</tr>
<tr>
<td><strong>Surface Profiles</strong></td>
<td>18</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>142</td>
</tr>
<tr>
<td><strong>%</strong></td>
<td>72.4</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Book's Chapters</th>
<th>Number of visuals used based on Baynes’s Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICONIC</td>
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<td>1</td>
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<tr>
<td>2</td>
<td>5</td>
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<td>3</td>
<td>0</td>
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<tr>
<td>4</td>
<td>0</td>
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<td>15</td>
<td>1</td>
</tr>
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<td>16</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>68</td>
</tr>
<tr>
<td><strong>%</strong></td>
<td>25.4</td>
</tr>
</tbody>
</table>

Table 7.4
ID Book: Materials and Design (Ashby and Johnson, 2004)

Table 7.5
ED Book: Materials Selection in Mechanical Design (Ashby, 2005)
Lens-2: Graphical Strategies on the 2 chapters of the ED and ID books

The ID book used various types of graphical strategies for its VTIs throughout the 2 chapters for a variety communication impact. The strategies utilised comprised all categories of PICTORIAL, SEQUENTIAL, SYMBOLIC, CAD and others beside those mentioned, e.g. sequential and ordinary tables (analysed results displayed in Table 7.6). However, the VTIs used in the ED book were confined to mainly SEQUENTIAL diagrammatic representations, with only left a small amount of ABSTRACT graphs and diagrams (analysed results shown in Table 7.7).

<table>
<thead>
<tr>
<th>No</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PICTORIAL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GA</td>
</tr>
</tbody>
</table>

**Introduction Chapter**

1. Interaction sketch
   - * *
   - *
   - *
   - *

2. Cause-and-effect diagram
   - *
   - *
   - *
   - *

3. Package flowchart
   - *
   - *
   - *

4. Sequential drawing diagram
   - *
   - *
   - *

5. Product sketch and photograph/portrait
   - *
   - *

**Table 7.6 continues on next page...**
### Table 7.6: VTIs Used in ID Book - Lens-2 (Danos's Taxonomy of Graphicacy)

<table>
<thead>
<tr>
<th>No</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>PICTORIAL</th>
<th>SEQUENTIAL</th>
<th>SYMBOLIC</th>
<th>CAD</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>GA</td>
<td>DR</td>
<td>DG</td>
<td>CT</td>
<td>ST</td>
</tr>
<tr>
<td>6</td>
<td>Product photograph/portrait</td>
<td><img src="image-1" alt="Image" /></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Product photograph/portrait</td>
<td><img src="image-2" alt="Image" /></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Introduction Chapter

1. Product photograph

#### Design Process Chapter

1. Product photograph

2. Sketch/drawing diagram

3. Various graphs and photograph

4. Package flowchart table

5. Bubble diagram

6. Detailed sketches

---

**GA**=graphic arts; **DR**=drawings; **DG**=diagrams; **CT**=cartoons; **ST**=storyboard; **FD**=flow diagrams; **SD**=spider diagrams; **AB**=abstract; **SP**=spatial; **CAD**=computer-aided-design.

*Table 7.6 continues on next page...*
An example interpretation of the VTIs analysis using Lens-2 *(Graphical Strategies)*

Based on the results in Table 7.6 *(Introduction chapter, item no. 4; an enlarged version Figure 7.11)* the almost realistic representation drawings or sketches aspect in the diagram falls into the category of PICTORIAL, which also possesses *graphic arts, drawings* and *general diagram* qualities. As the drawings formed a *flow diagram* and provide a *story* (a sequence direction of a process), it is then classified as SEQUENTIAL. Ultimately, certain parts of the drawings are symbols for objects and processes, as well as the overall diagram implying certain *abstract* messages, thus, making the overall depiction – a SYMBOLIC representation.

### Table 7.6

Analysis of the VTIs in *ID Book*, using Lens-2 *(Graphical Strategies)*

<table>
<thead>
<tr>
<th>No</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>PICTORIAL</th>
<th>SEQUENTIAL</th>
<th>SYMBOLIC</th>
<th>CAD</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Message photograph</td>
<td>![Image]</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Product photograph/portrait</td>
<td>![Image]</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Relational table</td>
<td>![Image]</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Message graphic arts</td>
<td>![Image]</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GA=*graphic arts*; DR=*drawings*; DG=*diagrams*; CT=*cartoons*; ST=*storyboard*; FD=*flow diagrams*; SD=*spider diagrams*; AB=*abstract*; SP=*spatial*; CAD=*computer-aided-design*.
<table>
<thead>
<tr>
<th>No</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
<th>PICTORIAL</th>
<th>SEQUENTIAL</th>
<th>SYMBOLIC</th>
<th>CAD</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>GA</td>
<td>DR</td>
<td>DG</td>
<td>CT</td>
<td>ST</td>
</tr>
<tr>
<td>1</td>
<td>Narrative-time chart</td>
<td><img src="image1" alt="Narrative-time chart" /></td>
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<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Product photograph/portrait</td>
<td><img src="image2" alt="Product photograph/portrait" /></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Comparison table</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Table 7.7 continues on next page...**

GA=graphic arts; DR=drawings; DG=diagrams; CT=cartoons; ST=storyboard; FD=flow diagrams; SD=spider diagrams; AB=abstract; SP=spatial; CAD=computer-aided-design.
### Table 7.7
Analysis of the VTIs in ED Book, using Lens-2 (Graphical Strategies)

<table>
<thead>
<tr>
<th>No</th>
<th>Descriptions/Names of VTI</th>
<th>VTI Samples</th>
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<th>SEQUENTIAL</th>
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<th>CAD</th>
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<tr>
<td>No</td>
<td></td>
<td></td>
<td>GA</td>
<td>DR</td>
<td>DG</td>
<td>CT</td>
<td>ST</td>
</tr>
<tr>
<td>6</td>
<td>Interaction diagram</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Drawing</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
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<td>8</td>
<td>Diagrammatic drawing</td>
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<td>*</td>
</tr>
<tr>
<td>9</td>
<td>Product photograph/portrait</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Collaboration diagram</td>
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</tr>
</tbody>
</table>

GA=graphic arts; DR=drawings; DG=diagrams; CT=cartoons; ST=storyboard; FD=flow diagrams; SD=spider diagrams; AB=abstract; SP=spatial; CAD=computer-aided-design.
An example interpretation of the VTIs analysis using Lens-2 (Graphical Strategies)

The results in Tables 7.6 (for ID Introduction chapter, item no. 2; an enlarge version Figure 7.13) and 7.7 (for ED Design Process Chapter, item no. 1; an enlarge version Figure 7.14) would be interpreted in this section. The ‘design process’ diagram for both ED and ID, as presented by (Ashby 2005, p. 13; Ashby and Johnson 2004, p. 8) beginning with identification of a ‘market need’ or a ‘new idea’; then, the stages of ‘concept’, ‘embodiment’ and ‘detailed’ design development; and ended with a full ‘product specification’ that fulfils the need or embodies the idea. The diagrams used to depict the idea of ‘design process’ for the ED and ID books are very different from one another, e.g. Figures 7.13 and 7.14.

These two depictions have made two different visual statements to communicate the essence of their design processes to their different intended audiences.

Figure 7.13 was intended for the ID students, which represented in a non-linear circular sequence, depicting the ideas of inputs coming from various perspectives and leading to the outputs of the consequences of designing: production, use and disposal. The overall visual suggests that all aspects are important and contribute to the final outcomes. Essentially, design for the ID students is depicted as sitting in the centre of a more complex social and cultural context.
In terms of its *graphicacy strategies* used in Figure 7.13, they were not just representing a plain *flow diagram* (SEQUENTIAL) that impart an intended message or *story* (like a *storyboard* that in the category of SEQUENTIAL), but also utilise *abstract* (SYMBOLIC) visual elements (depicted by *drawings* and *graphics* – PICTORIAL element), as well as arrows that arranged in a particular *spatial* (SYMBOLIC) setup to show a *general diagrammatic* (PICTORIAL) process condition. As a result, it was considered as utilising PICTORIAL, SEQUENTIAL, and SYMBOLIC categories of graphicacy strategies to enhance the total visual impact in communicating its designing message (or the technological information on this research context).

On the other hand, Figure 7.14 that was intended for the ED students was illustrated in a linear step-by-step sequence of process. Descriptions of development at each stage of the process were also shown as a direct input, which implied a simple and straightforward one-way flow of important stages.

The *graphicacy strategies* used in Figure 7.14 were, in fact, presented in the form of a *flow diagram* under the graphicacy category of SEQUENTIAL with nothing else of other strategy applied to its straightforward information.

Lens-3: *Graphical Techniques on the 2 chapters of the ED and ID books*

It was found that the selected 2 chapters only have one sample of the visual statistical information in the ED book, but none in the ID book; therefore, the analysis was done only on 2 selected VTIs (one from ED book and one from ID book) as sample analysis, but not to all VTIs used throughout the 2 chapters. The selected sample from the ED book was the only statistical VTI, and another non-statistical VTI was selected from ID book (as a trial analysis). They were viewed and analysed in terms of their graphical techniques via this third lens.
Figure 7.15 (from ED book) was analysed through the Lens-3 techniques (based on Tufte, 1990; 2006) in terms of ‘layering and separation of data’; ‘narrative of space and time’; ‘links and casual arrows’; and ‘coherence of words, number and images’ (as mentioned in section 2.6, Figure 2.22, Chapter 2; visual reference can be found in Appendix 2.4). The hierarchy of the information in the graph (Figure 7.15) allowed the viewer comfortably to compare several levels of data, thus, making it easy to be comprehended. This meant the layering and separation of data was effectively achieved. Its narrative of space and time was clearly visible and precisely outlined, which integrated statistical and verbal descriptions into one data set. The used of links and casual arrows helped to enhance the connection and relationship of information. The usage of words, number and images were cohered to one another in terms of readable text size, weight and spacing, therefore, providing a pleasant reading atmosphere as the information was hierarchically visible.
Figure 7.16 (from ID book) was analysed based on the techniques of ‘layering and separation of data’; ‘colour and information’; ‘links and casual arrows’; and ‘coherence of words, number and images’ (mentioned in section 2.6, Figure 2.22, Chapter 2; visual reference as in Appendix 2.4). The layering and separation of data or information was presented in a very subtle way, hence resulting the viewer in needing more time to make connection of the relationship. However, the form or structure of the diagram clearly suggested various sources from different points of perspectives. Single colour depiction and the usage of words in a very subtle manner looked and felt comfortable, but these failed to bring up important information or provide layers of information. Links and casual arrows were the key feature to the overall diagram message; however, they were too fine to be noticed for their differences in directions, hence needed a longer time to read.
Four visual representations (2 from each book) were selected to be analysed under this observation lens. This decision was made as the selected 2 pairs of visuals were sufficient to illustrate the key focus of the KEPs of VCT for the intention of this case study. The first pair of visuals was found to have space for improvement in terms of the VCT quality (analysed in Tables 7.8) in order to create a better visual impact for an immediate communication; thus, it was selected for redesign and further investigation in the VTI questionnaire survey.

### Table 7.8

<table>
<thead>
<tr>
<th>ED Visual</th>
<th>ID Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pair-1</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**KEP-1 [COMPARE > RELATIONSHIP]**

Beside the linear flow diagram with arrows to provide CONNECTION of RELATIONSHIP, there is no other visual guide to aid the COMPARISON and making connection for the purpose of communication. Thus, it requires more time to read every single word and comprehend the message.

**KEP-4 [SIMPLE design > COMPLEX data]**

SIMPLE in flow diagram form that incorporates MUCH INFORMATION, thus can be considered achieved this key principle.

The detailed analysis using the 4th lens (KEPs of VCT) for this visual was explained in section 4.3.2, Chapter 4.

Summary of the key issues:
- Visual guidance (arrows) is too subtle to be noticed, thus decreased the CONNECTION of RELATIONSHIP impact and readability in an immediate manner.

Table 7.8 continues on next page...
The second pair of visuals was found to have their own qualities of communication, and had similar pattern of good practice of the VCT (analysed in Table 7.8). Therefore, it was decided not to be redesigned, but was thought to be intriguing to investigate their preferences amongst ID and ED students in terms of the effective VC, and features that caught their attention and enabled them to understand the information presented. This was intended to examine the practical aspect of the KEPs applied.

**KEP-1 [COMPARE > RELATIONSHIP]**
Both have sufficient visual elements (slightly more in ID visual) to guide the COMPARISON that allow CONNECTION and RELATIONSHIP of each data to be revealed, therefore, eases the readability.

**KEP-2 [FORM > FUNCTION]**
Table is a good FORM that able to accentuate its FUNCTION to encourage viewer in making connection and understand the relationship and message embedded.

**KEP-3 [PRECISE > ACCURACY/TRUTH]**
The PRECISE data and matrix (code of dots or numbers) are almost indicating the TRUTH/ACCURATE spots of connection from one data to another.

**KEP-4 [SIMPLE design > COMPLEX data]**
SIMPLE table format together with text or visual guidance, have effectively provided MUCH INFORMATION to be imparted in a set of visual representation.

Table 7.8
Analysis of 2 Pairs of Visual Representations using the 4th Lens: KEPs of VCT
7.3.2 Results of VTIs analyses and redesigns

The analyses and redesigns of the selected representations are detailed in sections 4.3.1 until 4.3.7, Chapter 4. Table 7.9 summarised the outcomes of the redesigns from the existing representations:

<table>
<thead>
<tr>
<th>Existing Representations</th>
<th>Redesigned Version, applying the KEPs</th>
</tr>
</thead>
</table>

Table 7.9 continues on next page...
Table 7.9 continues on next page...
Table 7.9

Existing versus redesign version of the materials technology representations
7.3.3 **Results of questionnaire survey**

The quantitative and qualitative results of the VTI questionnaire survey are shown from Tables 7.10 to 7.15 (the comparative findings between LDS and METU in one page; and between PiS and LDS on the following page) in the order of each set of questions. There will be also a reminder or display of each set of the question or relative pairs of visuals (Figures 7.17 to 7.23) before the reported results. It is reported in this way to ease the comparison of the findings from the sources of data collected in corresponding to each set of questions, as well as the academic levels of the respondents. Table 7.16 summaries the numerical data of the respondents’ selection of VTI between existing and redesigned versions or between ED and ID visuals.

**SECTION A: Personal/Background Information**

1. Name (optional):
   *(in case the research analysis needs clarification; the research report will be remained anonymous)*

2. Gender:
   
<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
</table>

3. Age Group:
   
   | 18-25 | 26-33 | 34-41 | 42-49 | 50+ |

4. Country of growing up:

5. Programmes/Courses currently studied:

6. Prior Experience, relating to visual education: *(eg GCSE; AS/A2 Levels; Foundation Courses in Arts, D&T, Pastimes in Art, Photography, etc.)*

7. Which learning medium do you prefer? *(one that is most relevant to you)*
   
   | Visual Information | Auditory Information | Text Information | Physical Experience |

8. Email Address (optional):
   *(in case the research analysis needs clarification)*

**SECTION B: Disposition Towards Visual Information**

1. Which types of visual tools are those that you use most often in your work? *(and circle those relevant to you)*

   - **ICONIC:** Sketch; Drawing; Illustration; 2D/3D Model; Product Photograph; Technical Drawing
   - **SYMBOLIC:** Symbols; Pie Chart; Bar Chart; Mathematical Formula; Graph; Diagrams; Visual Matrix as shown below:
   
   - eg: visual mathematical technique; Eco Design Web; Graphical Statics; etc.

   - **ANALOGUE:** Storyboard; Map; Annotation; Exploded; Dialogue Box; Flowchart; Table

---

Figure 7.17

VTI Questionnaire: Sections A and B
2. By comparing the visual representations above, answer the following questions from 2.1 until 2.6:

2.1 What is the key message that the visuals H and I imply?

2.2 How valuable is the message in 2.1 to your designing? (✓ one only)

Not Important  Some Importance  Important  Very Important

2.3 By comparing visuals H and I, which one do you find is more effective in conveying its message? (✓ one only)

Visual H  Visual I

2.4 Which features catch your attention in the visual of your choice in 2.3? (Please state them in order if possible)

2.5 Which features of the visual of your choice in 2.3 or 2.4 are key to enabling your understanding?

2.6 Do you have any other comment on these visuals?

Figure 7.18
VTI Questionnaire: Question 2
(Image H: Material Languages cited in Pedgley 2010, p. 347)
**Question 2:**

**Effective in conveying message:**
- LDS (10 ID Master Students)
  - 3 females; 7 males.
  - 3 from UK; 1-USA; 2-Russia; 2-China; 1-Taiwan; 1-Moldova.
  - 3 declare as visual learners; 7 as physical experience learners.

- METU (12 ID Master Students)
  - 4 females; 8 males.
  - 1 from UK; 1-Azerbaijan; 10-Turkey.
  - 6 declare as visual learners; 2-text information; 2-physical experience; 1-visual + physical; and 1 visual + auditory.

- 8 are more familiar with ICONIC visual tools; 1-SYMBOLIC; 1-ICONIC & ANALOGUE.

<table>
<thead>
<tr>
<th>1 chose existing visual (H)</th>
<th>7 chose redesigned visual (I)</th>
<th>6 chose existing visual (H)</th>
<th>6 chose redesigned visual (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 did not answer</td>
<td>1 did not understand; 2 partially understood; 4 understood.</td>
<td>5 understood; and 1 partially understood the message.</td>
<td>All 6 understood the message.</td>
</tr>
</tbody>
</table>

**Understanding the message:**
- LDS (10 ID Master Students)
  - She did not understand.

- METU (12 ID Master Students)
  - She thinks having some importance to her practice.

- 2 out of the 4 that understood thought the visual is important; 2 valued them as having some importance.
- 1 thought it is important and the other felt got some importance (2 partially understood respondents).
- The one that did not understand valued it as not important.

- LDS (10 ID Master Students)
  - She did not understand.

- METU (12 ID Master Students)
  - 1 valued the visual as very important; 4 as important (including the 1 partially understood); and 1 felt it has some importance to the design practice.

- 3 of them believed the visual is very important; 1 thought is important; and 2 valued it as having some importance to their practice.

**Valuable for their designing practice:**
- LDS (10 ID Master Students)
  - She thinks having some importance to her practice.

- METU (12 ID Master Students)
  - The attention was on the overall simple representation.

- 6 of them also understood by the centred representation; 1 by the text on the green ring.

- LDS (10 ID Master Students)
  - 1 thought that visual ‘I’ is more appearing; 1 was not sure about the direction of arrows.

- METU (12 ID Master Students)
  - 4 caught their attention by the depictions of a machine and a hand; 1 by all images; 1 by the sensorial and technical symbols.

- 5 of them understood by the hand and machine; 1 by the division of diagram and arrows.

- LDS (10 ID Master Students)
  - 1 of them suggested the text on the green ring needs to be bigger.

<table>
<thead>
<tr>
<th>1 chose existing visual (H)</th>
<th>7 chose redesigned visual (I)</th>
<th>6 chose existing visual (H)</th>
<th>6 chose redesigned visual (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 did not answer</td>
<td>1 did not understand; 2 partially understood; 4 understood.</td>
<td>5 understood; and 1 partially understood the message.</td>
<td>All 6 understood the message.</td>
</tr>
</tbody>
</table>

**Key feature catching attention:**
- LDS (10 ID Master Students)
  - All 7 of them caught their attention by the centred representation.

- METU (12 ID Master Students)
  - 4 caught their attention by the icons of products in the centre; 2 by the sensorial and technical symbols.

- 3 understood by the sensorial and technical symbols; 3 by the centred vector images of products.

- LDS (10 ID Master Students)
  - 1 of them suggested the text on the green ring needs to be bigger.

- METU (12 ID Master Students)
  - 4 caught their attention by the depictions of a machine and a hand; 1 by all images; 1 by the sensorial and technical symbols.

- 5 of them understood by the hand and machine; 1 by the division of diagram and arrows.

**Key feature enabling understanding:**
- LDS (10 ID Master Students)
  - 6 of them also understood by the centred representation; 1 by the text on the green ring.

- METU (12 ID Master Students)
  - 3 understood by the sensorial and technical symbols; 3 by the centred vector images of products.

- LDS (10 ID Master Students)
  - 1 of them suggested the text on the green ring needs to be bigger.

- METU (12 ID Master Students)
  - 1 thought that visual ‘I’ is more appearing; 1 was not sure about the direction of arrows.

**Other comment:**
- LDS (10 ID Master Students)
  - 1 of them suggested the text on the green ring needs to be bigger.

- METU (12 ID Master Students)
  - 1 thought that visual ‘I’ is more appearing; 1 was not sure about the direction of arrows.

Table 7.10 continues on next page...
<table>
<thead>
<tr>
<th>Question 2:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective in conveying message:</td>
</tr>
<tr>
<td>3 chose existing visual (H); 1 did not answer</td>
</tr>
<tr>
<td>16 chose redesigned visual (I)</td>
</tr>
<tr>
<td>1 chose existing visual (H)</td>
</tr>
<tr>
<td>5 chose redesigned visual (I)</td>
</tr>
<tr>
<td>Understanding the message:</td>
</tr>
<tr>
<td>• All 3 partially understood the message.</td>
</tr>
<tr>
<td>• 4 understood the message; 5 partially understood; and 7 did not understand.</td>
</tr>
<tr>
<td>• He understood the message.</td>
</tr>
<tr>
<td>• 3 understood; and 2 partially understood the message.</td>
</tr>
<tr>
<td>Valuable for their designing practice:</td>
</tr>
<tr>
<td>• 1 thought it is very important; and 2 felt that are important.</td>
</tr>
<tr>
<td>• 14 of them valued the visual as very important and important; 1 thought it has some importance; and 1 did not answer.</td>
</tr>
<tr>
<td>• He thinks having some importance for his practice.</td>
</tr>
<tr>
<td>• 1 thought it is very important; 1 as important; and 1 as having some importance (understood group).</td>
</tr>
<tr>
<td>• 1 thought it is important and the other felt got some importance (partially understood group).</td>
</tr>
<tr>
<td>Key feature catches attention:</td>
</tr>
<tr>
<td>• 2 attracted by the visuals in the centre; 1 did not answer.</td>
</tr>
<tr>
<td>• 4 attracted by the colours, symbols and units represents technical aspect; 5 by the centred representation. 4 by colours and symbols; 2 by centred images; 1 did not answer (non-understood group).</td>
</tr>
<tr>
<td>• The attention was on the symbols in the centred circle.</td>
</tr>
<tr>
<td>• 3 understood respondents caught their attention by the coloured representation and simple diagram; 2 partially understood respondents by images in the centre.</td>
</tr>
<tr>
<td>Key feature enabling understanding:</td>
</tr>
<tr>
<td>• All 3 understood by the centred pictures.</td>
</tr>
<tr>
<td>• 11 understood by the centred representation; 3 by the symbols and units; 2 did not answer.</td>
</tr>
<tr>
<td>• He understood by the technical units and representations of human body parts.</td>
</tr>
<tr>
<td>• All 5 of them understood by the centred representation – the 2 ways of testing the materials.</td>
</tr>
<tr>
<td>Other comment:</td>
</tr>
<tr>
<td>• All 3 thought that the centred images also depicted recycle.</td>
</tr>
</tbody>
</table>

Table 7.10 Results of the VTI Questionnaire Survey (Question-2): Comparison of Data between LDS and METU; and PiS and LDS
Qualitative interpretation of the results from Table 7.10 (Question 2)

There were 3 important findings obtained from the VTls questionnaire survey that provided impact to the investigation of the KEPs of VCT. They are:

1. Understanding of the key message of the VTI
2. Key feature of the VTI that caught the viewer’s attention
3. Key feature of the VTI that enable the viewer to understand the message

This section only interprets results concerning the 3 important findings that support the KEPs of VCT for the redesigned VTI. This selection was because it was the most significant choice from the respondents (approximately 72% of respondents chose the redesign VTI). The qualitative findings obtained from the survey’s Question-2 were:

Message understanding:

- Half of the respondents understood the message embedded in the redesigned VTI; approximately 27% were partially understood; and 23% did not understand.

Attracted and understandable features:

- The most frequent mentioned features that caught the respondents’ attention were: the centred representation (a depiction of a bottle that is being hand-pressed and machine-pressed). Other features that caught the attention also included colours and symbols that represent sensorial and technical properties.

- Most of the respondents understood the VTI by the features of centred representation, symbols that represent sensorial properties and units that represent technical properties.

- Text, light indication of division lines and big arrows were also features that enabled some of the viewers to understand the VTI message.
Features related to KEPs of VCT:

- The depiction of a bottle that is being hand-pressed and machine-pressed (at the centred representation) encouraged the viewer to COMPARE and to reveal CONNECTIONS and RELATIONSHIPS between them. Additionally, the symbols that represent sensorial (by human body parts symbols) and technical properties (by numerical units) that placed at 2 sections of the circle (sensorial symbols at the top of the ring; technical units at the bottom of the ring that has 2 little division lines) also provided additional COMPARISON for the viewer to make CONNECTIONS and RELATIONSHIPS to the text provided in the diagram in order to make meaning out of it (this matched the emphasis of the KEP-1).

- The circular ring structure (some in full circle, and one with fine division lines), and the big arrows had emerged to a FORM that could FUNCTION (KEP-2) as a suggestion that there were different or separate ideas could be formed from one thing.

- The symbolic icons of human senses (using simple outlined drawing) and simple symbols of technical units, a ring that divided into 2 sections to place the 2 representational materials properties (the sensorial and technical) together with a full circle structure to place the hand- and machine-pressed representation, displayed a SIMPLE design structure, but carried a COMPLEX message of expressive and technical judgement about the materials properties. This demonstrates the application of KEP-4.
Figure 7.19
VTI Questionnaire: Visuals in Question 3
(Image B: Design Process cited in Ashby and Johnson 2004, p. 33)
**Question 3:**

<table>
<thead>
<tr>
<th>Effective in conveying message:</th>
<th>LDS (10 ID Master Students)</th>
<th>METU (12 ID Master Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None chose existing visual (B)</td>
<td>9 of them understood the message; 1 seems partially understood.</td>
<td>All 3 understood the message.</td>
</tr>
<tr>
<td>10 chose redesigned visual (C)</td>
<td>3 of them thought it is very important; 2 valued them as importance; 5 considered having some importance.</td>
<td>1 thought the visual is very important; 1 as importance and 1 as some importance.</td>
</tr>
<tr>
<td>3 chose existing visual (B)</td>
<td>6 of them understood the message; 3 seem partially understood.</td>
<td>2 valued them as very importance; 4 and those 3 partially understood thought it is important.</td>
</tr>
<tr>
<td>9 chose redesigned visual (C)</td>
<td>5 of them understood by the direction of arrows; 2 by colours and simple shapes that provide hierarchy manner; 2 by title and big arrow; 1 did not answer.</td>
<td>6 understood by the triangles that provide clear direction of arrows thus indicating its process, colours also help enhancing the understanding; 3 by the hierarchy of information (text).</td>
</tr>
<tr>
<td>Understanding the message:</td>
<td>6 of them caught their attention by the triangle shapes that formed the arrows; 3 by its colours and structure; 1 by the hierarchical level of information.</td>
<td>All 3 caught their attention by the centred circle and dotted lines of arrows.</td>
</tr>
<tr>
<td>Valuable for their designing practice:</td>
<td>5 chose redesigned visual (C)</td>
<td>6 caught their attention by the triangle, colours, clear direction and structure of inputs and output; 3 by the ‘design process’ cycle.</td>
</tr>
<tr>
<td>Key feature catches attention:</td>
<td>6 of them understood by the dotted arrows, shape and colour.</td>
<td>6 understood by the triangles that provide clear direction of arrows thus indicating its process, colours also help enhancing the understanding; 3 by the hierarchy of information (text).</td>
</tr>
<tr>
<td>Key feature enabling understanding:</td>
<td>1 of them thought both visuals B and C can be understood easily; however, visual C is clearer and more intent.</td>
<td>2 thought that the hierarchy of information is less effective than the visual ‘C’.</td>
</tr>
<tr>
<td>Other comment:</td>
<td>2 thought that the hierarchy of information is less effective than the visual ‘C’.</td>
<td>2 thought that arrows guidance in visuals ‘B’ is difficult to follow.</td>
</tr>
</tbody>
</table>

*Table 7.11 continues on next page...*
### Question 3:

#### Effective in conveying message:

<table>
<thead>
<tr>
<th>PiS (19 ED Diploma Students)</th>
<th>LDS (6 ED/BSc Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None chose existing visual (B)</td>
<td>1 chose existing visual (B)</td>
</tr>
<tr>
<td>19 chose redesigned visual (C)</td>
<td>He understood the message.</td>
</tr>
</tbody>
</table>

#### Understanding the message:

- 15 of them understood the message; 4 partially understood.
- He understood the message.
- All 5 understood the message.

#### Valuable for their designing practice:

- 4 thought it is very important; 9 treated it as important; and 2 felt it has some importance. 2 valued it as very important, and 2 as some importance (partially understood group)
- He thinks having some importance for his practice.
- 2 of them believed the visual is very important and 1 as important to their practice; 2 valued them as having some importance.

#### Key feature catches attention:

- 15 of them attracted by its simple layout and colours; 2 by the triangles and clear indication of arrows/directions; 2 did not answer.
- The attention was on the little arrows that go around the circle.
- 3 of them caught their attention by the colours and orientation of triangular shapes; 2 by clear layout and text.

#### Key feature enabling understanding:

- All 19 of them understood by the simple layout and directions of information.
- He understood by the concepts linked by the armed-shape diagram.
- All 5 of them understood by the arrows which provide clear process.

#### Other comment:

- 3 of them thought that arrows, dashed lines and output specification in visual ‘B’ are unclear, or else it will be a nicer diagram.
Qualitative interpretation of the results from Table 7.11 (Question 3)

This section only interprets results concerning the 3 important findings that support the KEPs of VCT for the redesigned VTI. This selection was because it was the most significant choice from the respondents (approximately 94% of respondents chose the redesign VTI). The qualitative findings obtained from the survey’s Question-3 were:

Message understanding:

- Most of the respondents understood the message embedded in the redesigned VTI, only about 18% were partially understood.

Attracted and understandable features:

- The most frequent mentioned features that caught the respondents’ attention were: the triangular shapes, arrows that create clear directions and the colours used. Other features that also attracted the attention included layout or structure of the diagram and hierarchy of information.

- Almost all of the respondents understood the VTI quite immediately by the features of triangular shapes that provided clear arrows for directions of inputs and outputs of the process.

- Colours and sizes of fonts that created a ‘layering and separation of data’ (Tufte’s graphical techniques in Lens-3) effect in the diagram structure, which also increased the hierarchy of information, had enabled the viewers to understand the information easily in some cases.
Features related to KEPs of VCT:

- The aspects of ‘clear directions’ of process by the ‘arrows’ and the effective ‘layering or hierarchy of information’ in the redesigned VTI, in fact, encouraged the viewer to COMPARE in order to reveal CONNECTIONS and RELATIONSHIPS within the data/information depicted in the VTI (this matched the emphasis of the KEP-1).

- The arrangement of ‘triangular shapes’ and the use of ‘colours and its tonality’ had created a total FORM, which was able to FUNCTION as another representational forms and meanings (KEP-2), e.g. in this case, as arrows and hints of directions to assist the comprehension while reading the VTI.

- The forms, layout arrangement, usage of font’s size and colours used in the redesigned VTI created a SIMPLE design structure that carry a COMPLEX message (KEP-4) behind the meaning of ‘design process’.
Figure 7.20
VTI Questionnaire: Visuals in Question 4
(Image D: Material/Process Matrix for Chairs cited in Ashby and Johnson 2004, p. 107;
<table>
<thead>
<tr>
<th>L D S  (10 ID Master Students)</th>
<th>METU  (12 ID Master Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question 4:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Effective in conveying message:</strong></td>
<td></td>
</tr>
<tr>
<td>1 chose visual E (from ED book)</td>
<td>9 chose visual D (from ID book)</td>
</tr>
<tr>
<td>• Partially understood.</td>
<td>• 7 of them understood; 2 seemed misunderstood the question as they answered the form of model the visual represent, instead of the messages that they carried.</td>
</tr>
<tr>
<td><strong>Understanding the message:</strong></td>
<td></td>
</tr>
<tr>
<td>• She thought that it is important.</td>
<td>• 2 of them thought it is very important; 2 as important; and 3 felt got some importance. 1 valued as importance and the other as some importance between the 2 that did not show understanding of visual.</td>
</tr>
<tr>
<td><strong>Valuable for their designing practice:</strong></td>
<td></td>
</tr>
<tr>
<td>• More information provided.</td>
<td>• All 9 of them caught their attention by the graphical depictions.</td>
</tr>
<tr>
<td><strong>Key feature catches attention:</strong></td>
<td></td>
</tr>
<tr>
<td>• Text on the left.</td>
<td>• All 9 of them understood by the connection of images and table of information.</td>
</tr>
<tr>
<td><strong>Key feature enabling understanding:</strong></td>
<td></td>
</tr>
<tr>
<td>• 1 of them found the format of visual E and those alike very difficult to read in general.</td>
<td></td>
</tr>
<tr>
<td><strong>Other comment:</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.12 continues on next page...
## Question 4:

### Effective in conveying message:

<table>
<thead>
<tr>
<th>PiS (19 ED Diploma Students)</th>
<th>LDS (6 ED/BSc Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 chose visual E (from ED book)</td>
<td>12 chose visual D (from ID book)</td>
</tr>
<tr>
<td>• 3 understood the message; 3 partially understood; and 1 did not understand.</td>
<td>• 6 understood and 3 partially understood the message; 3 seemed misunderstood the question as they answered the common format for the visuals, instead the messages that they carried.</td>
</tr>
</tbody>
</table>

### Understanding the message:

- 3 partially and 1 understood thought that it is very important; 1 valued it as important and 1 as some importance. 1 did not understand felt it is very important too.
- 5 thought it is very important, and 5 as important; 2 felt got some importance.
- He thinks the visual is very important for his practice.
- 1 of them believed the visual is very important and 4 valued as important to their practice.

### Valuable for their designing practice:

- All 7 attracted by E because it provided more details.
- All 12 caught their attention by the graphical depictions of chairs.
- He caught the attention by more details and big text.
- All 5 of them caught their attention by the illustration that easy to make connection with.

### Key feature catches attention:

- All 7 understood by the simple format of table.
- All 12 understood by the connection between depictions of chairs and the table matrix of information.
- He understood by the layout of table.
- 3 of them understood by the images and table; 2 by the coordination of numbers of images and table.

### Key feature enabling understanding:

- I thought that if could combine the visual ‘D’ and ‘E’ then it would be better.
- 5 of them indicated that the simple drawings and table at the side really help to make things easy to understand.
- I suggested that colours coordination perhaps could help to link the connection quicker.

### Other comment:

- 1 thought that if could combine the visual ‘D’ and ‘E’ then it would be better.
- 5 of them indicated that the simple drawings and table at the side really help to make things easy to understand.
- I suggested that colours coordination perhaps could help to link the connection quicker.

<table>
<thead>
<tr>
<th>7 chose visual E (from ED book)</th>
<th>12 chose visual D (from ID book)</th>
<th>1 chose visual E (from ED book)</th>
<th>5 chose visual D (from ID book)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• He understood the message.</td>
<td>• All 5 understood the message.</td>
<td>• All 5 of them caught their attention by the illustration that easy to make connection with.</td>
<td>• 3 of them understood by the images and table; 2 by the coordination of numbers of images and table.</td>
</tr>
</tbody>
</table>

Table 7.12 Results of the VTI Questionnaire Survey (Question-4): Comparison of Data between LDS and METU; and PiS and LDS
Qualitative interpretation of the results from Table 7.12 (Question 4)

This section interprets results concerning the 3 important findings that support the KEPs of VCT for the ID visual (due to approximately 81% of respondents choosing the ID visual). The qualitative findings obtained from the survey’s Question-4 were:

**Message understanding:**
- Most of the respondents (74%) understood the message embedded in the ID visual; about 13% were partially understood; and another 13% did not answer this question.

**Attracted and understandable features:**
- The illustration of various designs of the chairs was the feature that attracted the attention of all respondents.
- All respondents understood the VTI by comparing various designs of the chairs to the table provided next to the illustrations.
- Number coordination used in the table (showing the materials process) to represent a particular design of the chair was also indicated as visual element that made them understood the message.

**Features related to KEPs of VCT:**
- The illustrations of ‘chairs’ and the ‘materials process table’ that placed side-by-side, also the use of numbers to represent each design of chair, offered effective visual COMPARISON that revealed CONNECTIONS and RELATIONSHIPS about the designs, types of materials and the process required within the depiction of the VTI (this matched the emphasis of the KEP-1). As a result, the VTI was easily comprehended and had effectively served the purpose of communicating its technological information.
• The use of visual representations, numbers and table format served an effective information FORM that accentuated the message across the VTI, thus making the FUNCTION of communication (KEP-2) clear and PRECISE for telling TRUE (KEP-3) information about materials and their possible looks or designs and processes required.

• The VTI format was SIMPLE in the sense that having simple illustrations and a standard table to inform a numbers of messages, thus, matched the (KEP-4: SIMPLE in design form and COMPLEX in carrying data).
Figure 7.21
VTI Questionnaire: Visuals in Question 5
### Question 5:

<table>
<thead>
<tr>
<th>Effective in conveying message:</th>
<th>LDS (10 ID Master Students)</th>
<th>METU (12 ID Master Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 chose existing visual (G)</td>
<td>5 chose redesigned visual (F)</td>
<td>6 chose existing visual (G)</td>
</tr>
<tr>
<td><strong>Understanding the message:</strong></td>
<td>• All 5 understood the message.</td>
<td>• 3 understood the message; 2 partially understood; and 1 did not understand.</td>
</tr>
<tr>
<td>• 3 understood the message; and 2 partially understood.</td>
<td>• 2 valued the visual is very important (included 1 that did not understand); 4 as important.</td>
<td>• 5 understood the message; 1 partially understood.</td>
</tr>
<tr>
<td><strong>Valuable for their designing practice:</strong></td>
<td>• 2 of them thought it is important; and 3 valued it as some importance.</td>
<td>• 2 valued the visual is very important; and 4 as important (included the 1 partially understood).</td>
</tr>
<tr>
<td>• 4 of them thought it is very important; and 1 valued it as importance.</td>
<td>• 2 valued the visual is very important; and 4 as important (included the 1 partially understood).</td>
<td></td>
</tr>
<tr>
<td><strong>Key feature catches attention:</strong></td>
<td>• 4 of them caught their attention by the graphics representations or images; 1 by the city context.</td>
<td>• All 6 attracted by the simple circular shapes and typography.</td>
</tr>
<tr>
<td>• All 5 of them caught their attention by simple colours and form.</td>
<td>• All 6 attracted by the symbols, arrows and strong contrast.</td>
<td></td>
</tr>
<tr>
<td><strong>Key feature enabling understanding:</strong></td>
<td>• 4 of them understood by the graphics as they are easy to make connection with; 1 by the arrows and labelling.</td>
<td>• All 6 understood by the representational images and arrows.</td>
</tr>
<tr>
<td>• All 5 of them understood by text and arrows; 1 also by the dashed circular lines.</td>
<td>• All 6 indicated that pure typography or text made them understood.</td>
<td></td>
</tr>
<tr>
<td><strong>Other comment:</strong></td>
<td>• 1 thought the link between user and ‘meaning of material’ is quite confusing; 1 stated too much graphics in visual F distract the attention.</td>
<td></td>
</tr>
<tr>
<td>• 1 thought that the hierarchy of information in visual F needs refining.</td>
<td>• 3 felt that the visual representations in visual ‘F’ are too complicated and distracting.</td>
<td></td>
</tr>
<tr>
<td>• 4 indicated that visual ‘F’ can be understood even by images and arrows without text at first glance; 1 mentioned that the context in visual ‘G’ could not be noticed at first.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.13 continues on next page...
### Question 5:

<table>
<thead>
<tr>
<th></th>
<th><strong>PiS</strong> (19 ED Diploma Students)</th>
<th><strong>LDS</strong> (6 ED/BSc Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Important in conveying message:</strong></td>
<td>1 chose existing visual (G): He partially understood the message.</td>
<td>1 chose existing visual (G): He could not understand the message.</td>
</tr>
<tr>
<td></td>
<td>18 chose redesigned visual (F): 9 understood the message; 9 partially understood.</td>
<td>4 chose redesigned visual (F): 3 understood the message; 1 seems partially understood.</td>
</tr>
<tr>
<td><strong>Understanding the message:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• He partially understood the message.</td>
<td>• 9 understood the message; 9 partially understood.</td>
<td>• He could not understand the message.</td>
</tr>
<tr>
<td>• He thought that it is important for his practice.</td>
<td>• 3 valued it is very important; 4 as important; and 2 as some importance.</td>
<td>• He did not answer.</td>
</tr>
<tr>
<td><strong>Valuable for their designing practice:</strong></td>
<td></td>
<td>2 of them believed the visual is important and 1 valued as having some important to their practice; 1 partially understood respondent felt that it is very important to their practice.</td>
</tr>
<tr>
<td>• He thought that it is important for his practice.</td>
<td>• 3 valued it is very important; 4 as important; and 2 as some importance.</td>
<td></td>
</tr>
<tr>
<td>• He did not answer.</td>
<td>• He did not answer.</td>
<td></td>
</tr>
<tr>
<td><strong>Key feature catches attention:</strong></td>
<td>11 attracted by the graphics representations or images; 7 by the human icon, city background.</td>
<td>All 4 of them caught their attention by the human, colour and other images that making clear context.</td>
</tr>
<tr>
<td>• He attracted by simple mapping format.</td>
<td>• He caught the attention by simple shapes.</td>
<td></td>
</tr>
<tr>
<td><strong>Key feature enabling understanding:</strong></td>
<td>18 understood by the visual representation and text information.</td>
<td>3 of them understood by the layout and hierarchy of the graphics; 1 by the words ‘effects’ and ‘interaction’.</td>
</tr>
<tr>
<td>• He understood by the text information.</td>
<td>• Nothing helps him to understand.</td>
<td></td>
</tr>
<tr>
<td><strong>Other comments:</strong></td>
<td>6 thought that the extra visuals help to understand the message easier.</td>
<td>1 thought that visual ‘G’ is depicted too abstract, thus it is hard to understand.</td>
</tr>
<tr>
<td>• 6 thought that the extra visuals help to understand the message easier.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.13 Results of the VTI Questionnaire Survey (Question-5): Comparison of Data between LDS and METU; and PiS and LDS
Qualitative interpretation of the results from Table 7.13 (Question 5)

This section interprets results concerning the 3 important findings that support the KEPs of VCT for the redesigned VTI (due to 70% of respondents choosing the redesign). The qualitative findings obtained from the survey’s Question-5 were:

Message understanding:
- Most of the respondents (67%) understood the message embedded in the redesigned VTI; 33% of them were partially understood.

Attracted and understandable features:
- The most frequent mentioned features that caught the respondents’ attention were: human icons and other graphic representations for context, especially the cityscape. Other features that also attracted the attention included arrows and strong contrast or colours.
- Most of the respondents understood the VTI by connecting the graphic representations, arrows and text provided. Some respondents understood by only the connection within the overall layout or hierarchy of graphics, graphics and arrows.

Features related to KEPs of VCT:
- The graphic icons or representations with the help of arrows provided effective visual COMPARISON that enables the viewer to reveal CONNECTIONS and RELATIONSHIPS within them. With the additional text provided, the connection and relationship were further enriched. This matched the emphasis of the KEP-1.
- The use of graphics representation (FORM) offered easy comprehended (FUNCTION) context to the VTI, thus enabling the viewer to understand the meaning or message more quickly. This matched the emphasis of the KEP-2.
Figure 7.22
VTI Questionnaire: Visuals in Question 6
Table 7.14 continues on next page...
### Question 6:

<table>
<thead>
<tr>
<th>Effective in conveying message</th>
<th>Understanding the message</th>
<th>Valuable for their designing practice</th>
<th>Key feature catches attention</th>
<th>Key feature enabling understanding</th>
<th>Other comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PiS</strong> (19 ED Diploma Students)</td>
<td><strong>LDS</strong> (6 ED/BSc Students)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6 chose existing visual (J)</strong></td>
<td><strong>13 chose redesigned visual (K)</strong></td>
<td><strong>2 chose existing visual (J)</strong></td>
<td><strong>4 chose redesigned visual (K)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 2 partially understood the message; 4 did not understand.</td>
<td>• 4 of them understood the message; 9 partially understood.</td>
<td>• Both seemed understood the message.</td>
<td>• 3 understood the message; 1 seems partially understood.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Understanding the message:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 1 thought it is very important; 3 considered as important; and 2 felt it has some importance.</td>
<td>• 4 thought it is very important; 8 valued as important; and 1 felt it has some importance.</td>
<td>• Both thought the visual has some importance to their practice.</td>
<td>• 4 of them believed that the visual has some important to their practice.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Valuable for their designing practice:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• All 6 attracted by the simple 3-axes graph.</td>
<td>• 7 attracted by its colourful cards; 6 by the arrangement of information.</td>
<td>• They caught the attention by three variables are shown in one 3D graph.</td>
<td>• All 4 of them caught their attention by the colours and table.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Key feature enabling understanding:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• All 6 understood by the graph and annotations.</td>
<td>• All 13 understood by the simple coloured cards and table format.</td>
<td>• 1 understood by the screen; the other said don’t know.</td>
<td>• All 4 of them understood by the colours, matrix and table.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other comment:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• 4 thought that the coloured cards are very helpful format and the overall information is very useful for their design practice.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.14 Results of the VTI Questionnaire Survey (Question-6): Comparison of Data between LDS and METU; and PiS and LDS
Qualitative interpretation of the results from Table 7.14 (Question 6)

This section interprets results concerning the 3 important findings that support the KEPS of VCT for the redesigned VTI (due to approximately 64% of respondents choosing the redesign). The qualitative findings obtained from the survey’s Question-6 were:

**Message understanding:**
- Most of the respondents (63%) understood the message embedded in the redesigned VTI; about 37% partially understood the message.

**Attracted and understandable features:**
- The coloured cards and the table format of the colour-material-technology information were the features that attracted the attention of all respondents.
- All respondents understood the VTI by comparing the material axis against technology axis, corresponding to the colour indication (visually) on the card itself (as all of them mentioned the coloured card format, and table matrix and its information).

**Features related to KEPS of VCT:**
- The 2 axes of materials and technology and those separated cards that in different colours offered visually effective guidelines for viewer to COMPARE their CONNECTIONS and RELATIONSHIPS. This matched the emphasis of the KEP-1.
- The sizes and layering of the coloured cards together with the arrow created an efficient shape of FORM that accentuated the FUNCTION (KEP-2). The cards were arranged one after the other in depth in visual space (as the arrow suggested the third dimension), hence implying that there were many coloured cards which could put in for references of materials and their technology to produce such colours.
The VTI structure was SIMPLE in the sense of having simple table and colour formats, but the overall message could carry a number of information (COMPLEX data) regarding types of materials, colours and the technology to produce those colours. This matched the KEP-4 of being SIMPLE in design form and COMPLEX in carrying data.
Figure 7.23
Questionnaire: Visuals in Question 7
(Image L: Validated Material Selection Activities (MSA) Model; Information Sources Used in Materials Selection cited in van Kesteren 2010, p. 326)
**Question 7:**

<table>
<thead>
<tr>
<th>Effective in conveying message:</th>
<th>LDS (10 ID Master Students)</th>
<th>METU (12 ID Master Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 chose existing visual (L)</td>
<td>8 of them understood the messages; 1 did not answer.</td>
<td>Both understood the message.</td>
</tr>
<tr>
<td>9 chose redesigned visual (M)</td>
<td>★ She partially understood the message.</td>
<td>★ 4 understood the messages; and 6 partially understood.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Understanding the message:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>★ She partially understood the message.</td>
<td>★ 8 of them understood the messages; 1 did not answer.</td>
<td>★ Both understood the message.</td>
</tr>
<tr>
<td>★ Both understood the message.</td>
<td>★ 3 of them believed it is important; 5 and the 1 did not answer thought that it has some important to their designing works.</td>
<td>★ Both valued it as very important to their designing works.</td>
</tr>
<tr>
<td>★ 4 understood the messages; and 6 partially understood.</td>
<td>★ Both valued it as very important to their designing works.</td>
<td>★ 1 treated it as very important, 2 as important, and 1 as some importance (among the 4 understood respondents); 2 as very important and 4 as important (among the partially understood respondents).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Valuable for their designing practice:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>★ She felt that it is important.</td>
<td>★ 3 of them believed it is important; 5 and the 1 did not answer thought that it has some important to their designing works.</td>
<td>★ Both valued it as very important to their designing works.</td>
</tr>
<tr>
<td>★ Both valued it as very important to their designing works.</td>
<td>★ Both valued it as very important to their designing works.</td>
<td>★ 1 treated it as very important, 2 as important, and 1 as some importance (among the 4 understood respondents); 2 as very important and 4 as important (among the partially understood respondents).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key feature catches attention:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>★ The presentation.</td>
<td>★ 8 of them caught their attention by the colours and simple layout; 1 by the people silhouettes and grey boxes of text.</td>
<td>★ Both attracted by the individual representation of each stakeholder.</td>
</tr>
<tr>
<td>★ Both attracted by the individual representation of each stakeholder.</td>
<td>★ Both attracted by the individual representation of each stakeholder.</td>
<td>★ All 10 attracted by the overall structure of the diagram and 1 also by its colours and grey boxes of text.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key feature enabling understanding:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>★ The logic.</td>
<td>★ 6 of them understood by the arrows and connections, and the flow of ideas and information.</td>
<td>★ 1 understood by the separated diagrams; the other by the explanation below the diagrams.</td>
</tr>
<tr>
<td>★ 9 understood by the overall structure, hierarchy of information and directions of arrows; 1 did not answer.</td>
<td>★ 9 understood by the overall structure, hierarchy of information and directions of arrows; 1 did not answer.</td>
<td>★ 6 thought that visual ‘L’ is too complicated because of its individual representation of each stakeholder and the arrows; 1 felt that it is not necessary to have 2 diagrams to tell the story.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other comment:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>★ 1 of them thought that visual ‘L’ is far too complex to understand; and visual ‘M’ is fairly ugly but the form and layout are simpler, thus it is more effective to be red and understood.</td>
<td>★ 6 thought that visual ‘L’ is too complicated because of its individual representation of each stakeholder and the arrows; 1 felt that it is not necessary to have 2 diagrams to tell the story.</td>
<td>★ 6 thought that visual ‘L’ is too complicated because of its individual representation of each stakeholder and the arrows; 1 felt that it is not necessary to have 2 diagrams to tell the story.</td>
</tr>
</tbody>
</table>
### Question 7:

**Effective in conveying message:**
- **PiS (19 ED Diploma Students):**
  - 4 chose existing visual (L); 1 didn't answer the entire set
  - 14 chose redesigned visual (M)
- **LDS (6 ED/BSc Students):**
  - 2 chose existing visual (L); 1 did not answer
  - 3 chose redesigned visual (M)

**Understanding the message:**
- **PiS (19 ED Diploma Students):**
  - All 4 partially understood the message.
  - 13 understood the messages; 1 partially understood.

**Valuable for their designing practice:**
- **PiS (19 ED Diploma Students):**
  - All 4 felt that it is important.
  - 7 believed it is very important; 6 valued it as important; and 1 thought that it has some important to the design practice.

**Key feature catches attention:**
- **PiS (19 ED Diploma Students):**
  - All 4 attracted by its presentation.
  - 5 attracted by the colours and forms; 3 by the people silhouettes; and 5 by the flow chart; 1 did not answer.

**Key feature enabling understanding:**
- **PiS (19 ED Diploma Students):**
  - All 4 understood by the 2 steps representation of the diagram.
  - 10 understood by the order/hierarchy of information; 3 by the text; 1 did not answer.

**Other comment:**
- **PiS (19 ED Diploma Students):**
  - 5 thought that visual ‘M’ is like a summary of the ‘L’, and its arrangement is easier to follow and understand.

**LDS (6 ED/BSc Students):**
- 1 understood the message; and 1 seems partially understood.
- All 3 understood the message.
- 7 believed it is very important; 6 valued it as important; and 1 thought that it has some important to the design practice.
- Various images of people attracted their attention; plus simple grey colour with statistics (partially understood respondent).
- Clear layout and text, arrows, representation of figures and clear distinction of phases attracted their attention.
- Flow of diagram that working downward made him understood (understood respondent); by human figures (partially understood respondent).
- Same as the above, and also the figures (and who they represent in the list of text) making the diagram easy to follow and understood by 3 of them.

- 1 thought that visual ‘L’ is difficult to understand because the connection lines and human figures are difficult to follow and to guess who they represent.

<table>
<thead>
<tr>
<th>Question 7:</th>
<th>PiS (19 ED Diploma Students)</th>
<th>LDS (6 ED/BSc Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective in conveying message:</td>
<td>4 chose existing visual (L); 1 didn’t answer the entire set</td>
<td>2 chose existing visual (L); 1 did not answer</td>
</tr>
<tr>
<td>Understanding the message:</td>
<td>All 4 partially understood the message.</td>
<td>All 3 understood the message.</td>
</tr>
<tr>
<td>Valuable for their designing practice:</td>
<td>All 4 felt that it is important.</td>
<td>2 of them believed it is important; and 1 thought that it has some important to their designing works.</td>
</tr>
<tr>
<td>Key feature catches attention:</td>
<td>All 4 attracted by its presentation.</td>
<td>Various images of people attracted their attention; plus simple grey colour with statistics (partially understood respondent).</td>
</tr>
<tr>
<td>Key feature enabling understanding:</td>
<td>All 4 understood by the 2 steps representation of the diagram.</td>
<td>Flow of diagram that working downward made him understood (understood respondent); by human figures (partially understood respondent).</td>
</tr>
<tr>
<td>Other comment:</td>
<td>5 thought that visual ‘M’ is like a summary of the ‘L’, and its arrangement is easier to follow and understand.</td>
<td>1 thought that visual ‘L’ is difficult to understand because the connection lines and human figures are difficult to follow and to guess who they represent.</td>
</tr>
</tbody>
</table>

Table 7.15 Results of the Diagram Questionnaire Survey (Question-7): Comparison of Data between LDS and METU; and PiS and LDS
Qualitative interpretation of the results from Table 7.15 (Question 7)

This section interprets results concerning the 3 important findings that support the KEPs of VCT for the redesigned VTI (due to 77% of respondents choosing the redesign). The qualitative findings obtained from the survey’s Question-7 were:

**Message understanding:**
- Most of the respondents (78%) understood the message embedded in the redesigned VTI; 19% partially understood the message; and approximately 3% did not answer the question.

**Attracted and understandable features:**
- The most frequent mentioned features that caught the respondents’ attention were: human icon (they called it people silhouettes or representation or figures), colours, grey boxes of text and the flow structure. Other features that attracted their attention included arrows and phases of information.
- Most respondents understood the VTI by comparing the phases of information (hierarchically presented visually and in text form), connection of arrows, and human icon with the list of who it represents.

**Features related to KEPs of VCT:**
- Three phases of information (distinguished by colours and form of structure), arrows, as well as the human icon (with a list of stakeholders on it) which placed against the panel of activity offered several visual elements for viewer to COMPARE in order to reveal the CONNECTIONS and RELATIONSHIPS among them. This matched the emphasis of the KEP-1.
- The SIMPLE flow diagram and arrows structures enable the COMPLEX information to be summarised in a set of data format which matched the emphasis of the KEP-4.
<table>
<thead>
<tr>
<th>Question (Q)</th>
<th>LDS (10 ID Master Students)</th>
<th>METU (12 ID Master Students)</th>
<th>PiS (19 ED Diploma Students)</th>
<th>LDS (6 ED/Bsc Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing vs. Redesign; or ED vs. ID visuals</td>
<td>6 vs. 6</td>
<td>3 vs. 16</td>
<td>1 vs. 5</td>
<td></td>
</tr>
<tr>
<td>Q2 (Figure 7.18)</td>
<td>1 vs. 7 (2 did not answer)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 vs. 10</td>
<td>3 vs. 9</td>
<td>0 vs. 19</td>
<td>1 vs. 5</td>
<td></td>
</tr>
<tr>
<td>Q3 (Figure 7.19)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 vs. 9</td>
<td>0 vs. 12</td>
<td>7 vs. 12</td>
<td>1 vs. 5</td>
<td></td>
</tr>
<tr>
<td>Q4 (Figure 7.20)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 vs. 5</td>
<td>6 vs. 6</td>
<td>1 vs. 18</td>
<td>1 vs. 4 (1 did not answer)</td>
<td></td>
</tr>
<tr>
<td>Q5 (Figure 7.21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 vs. 5</td>
<td>4 vs. 8</td>
<td>6 vs. 13</td>
<td>2 vs. 4</td>
<td></td>
</tr>
<tr>
<td>Q6 (Figure 7.22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 vs. 9</td>
<td>2 vs. 10</td>
<td>4 vs. 14 (1 did not answer)</td>
<td>2 vs. 3 (1 did not answer)</td>
<td></td>
</tr>
<tr>
<td>Q7 (Figure 7.23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.16
Summary of the VTI Questionnaire Survey Results: Comparison of Numerical Data between LDS and METU; and PiS and LDS
Table 7.17 summarises the overall results from the selection of more effective VTI comparing the existing (or ED) and redesigned (or ID) versions. Although there were 3 redesigned VTIs having equal selection between the existing and the redesigned in 2 groups of ID students (shown in Table 7.16), the overall results still concluded that all the redesigned VTIs were more effective in conveying their messages as compared to the existing versions (displayed in Table 7.17), for both ID and ED student-groups in general.

The findings also did not show any difference in culture (either ID or ED educational background; or differences in growing up countries in different regions) influenced the results of reading VTI (Tables 7.10 to 7.16). However, there was a little evidence of differences in term level of education in the ID groups. Respondents (who were at a higher level of educational background) seemed to have the potential to prefer more ABSTRACT VTI, and were able to comprehend abstract messages (Tables 7.16; related survey questions: 2, 5 and 6; related Figures: 7.17, 7.20 and 7.21).

<table>
<thead>
<tr>
<th>Question (Q)</th>
<th>Existing VTI; or ED Visual</th>
<th>Redesigned VTI; or ID Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Understanding</td>
<td>Effective Visual</td>
</tr>
<tr>
<td>Q2 (Figure 7.18)</td>
<td>54%</td>
<td>28%</td>
</tr>
<tr>
<td>Q3 (Figure 7.19)</td>
<td>100%</td>
<td>9%</td>
</tr>
<tr>
<td>Q4 (Figure 7.20)</td>
<td>44%</td>
<td>19%</td>
</tr>
<tr>
<td>Q5 (Figure 7.21)</td>
<td>46%</td>
<td>30%</td>
</tr>
<tr>
<td>Q6 (Figure 7.22)</td>
<td>35%</td>
<td>36%</td>
</tr>
<tr>
<td>Q7 (Figure 7.23)</td>
<td>33%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Table 7.17
Summary of the VTI Questionnaire Survey Results: Comparison of the Selection of Effective VTI between Existing/ED and Redesigned/ID VTI
### Results of validation: the experts discussion

The findings from the materials experts from 3 different higher institutions were as presented in Table 7.18, and as based on the 3 main questions shown in the table.

<table>
<thead>
<tr>
<th>Validation Discussion with Materials Experts</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
</tr>
<tr>
<td>LU, UK</td>
</tr>
</tbody>
</table>

**Question-1:** Do you think ID and ED students need different styles of VTI to understand information concerning materials? (in terms of: representational models; graphical strategies and/or techniques)

**Answers:**
- No, I would not expect to use different VTI for ID and ED students.
- In fact, the differences between ID and ED students were due to their exposure of educational and training background. Without exposing visual elements to the ED students in the first place, I would guess they would reject the visuals, as they have been trained in a more conceptual way throughout their education. However, once they have been exposed to visuals as my students had, they would accept and prefer it. This is because I think the nature of people’s minds does work or see visuals in the first instance. This fact, actually, can be observed from little kids.

**In terms of representational models:**
- I would say yes, ID and ED do need different styles of VTI for materials, with regard to the representational models used. This is because in my view ID and ED are significantly different disciplines in the way that they use materials and for what purposes. ID is heavily concerned with the aesthetics of materials, and the aesthetics of interaction between people and materials, and so its core concern is how materials influence people’s experiences of products, either in use or as objects to behold. On the other hand, ED is occupied heavily with the performance of components that interact with other components, rather than interfacing with users. From this viewpoint, it would follow that material representational models should be obviously user-centred for ID, but this emphasis is not necessary for ED.

**Yes, I would expect ID and ED students needed different styles of VTI to understand information about materials. This covers representational models, graphical strategies and techniques of those VTIs used. Because ID and ED are very different one another in the nature of their role.**
## Validation Discussion with Materials Experts

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU, UK</td>
<td>METU, Turkey</td>
<td>PiS, Malaysia</td>
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### Question-1: Continue...

**Answers:**

In terms of graphical strategies and techniques:

- I think good, clear, comprehensible graphics are necessary for both ID and ED. In my experience ED VTI tends to be over-specified or over-complicated for ID; perhaps too 'technical' and numerical in its graphical strategies and techniques. ID is less appreciative of such 'technification' and, I believe, views simplified and illustrative/iconic methods more highly.

### Question-2: Were the results presented as you would have expected? (in terms of: any different KEPS should applied to ID and ED students?)

**Answers:**

- Yes, I am not surprised to see the visual approach attained from the redesigned (VTIs) were more communicable between the 2 groups of students among the undergrads, as most of the redesigns were provided with visual associations and depicted the real world complexity.

- Whereas, the masters were slightly more drawn to the existing visuals in some cases. I think it is because, the masters are more mature, and are already in a more conceptual thinking stage, thus, trying to jump out from the real world, and so abstract visuals could be understandable and preferred by them.

- The increase in effectiveness from existing to redesigned visuals was higher than I expected. In other words, it is quite surprising (at least to someone without a VCT background) that relatively subtle changes in graphics can make such dramatic influence on effectiveness. It was especially interesting that all redesigns resulted in an increase in effectiveness (% increase values, and mean % increase would be useful to add). For understanding of the visuals, clearly the results are more mixed. Certainly I would expect an increase in understanding in all cases, so I am curious as to why Figure 7.17 and 7.18 resulted in no increase, or reduction. Probably 'understanding' is more important than 'effective'?

- No. I would have thought that ED students would understand better the more technical diagrams with less graphics representation. It is quite surprising that the redesign visuals increased in effectiveness and understanding.

- I would expect also the visuals used in presenting messages of materials to have applied different principles of graphics for ID and ED students.

Table 7.18 continues on next page...
Validation Discussion with Materials Experts

<table>
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<th>(1)</th>
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<td>LU, UK</td>
<td>METU, Turkey</td>
<td>PiS, Malaysia</td>
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**Question-3:** Did you expect to see that there was no evidence of cultural differences influencing understanding of VTI (or VCT)?

**Answers:**

- **LU, UK:** Yes, I expected the preferred VTIs should have no difference culturally. Visual information should be quite the same in communicating basic ideas. Example, i-Pad is globally accepted as visually appealing and functional.

- **METU, Turkey:** I think this is not too surprising, given that the design schools selected for the study all have a relatively high technical training or expectancy from graduates. Similarly, students from these institutions probably have contact with the same kinds of textbooks, web resources, databases etc. So if their exposure is basically the same, it is reasonable to assume that their understanding of VCT (materials) should be very similar. Certainly I have not observed personally any major differences in comprehension of materials topics, vocabulary or materials selection reasoning between UK (LDS) and TR (METU) ID students.

- **PiS, Malaysia:** Yes, I would expect that there is no difference between cultures in reading VTIs in technical terms or purposes. Because the technical education all around the world should have similar basis of contents, differences could be about the detailed approaches and activities. Thus, I would assume this applies to visual tools used in this educational context.

Table 7.18
Findings from the Materials Experts
7.4 Reliability and Validity of the Case Study Results

The reliability of the studied results in Case Study-3 was achieved via the triangulation as demonstrated in Figure 7.24. The first result was gathered through the survey of literature, which found the essential role of materials technology for current sophisticated market’s needs, and the new emergent agenda of sensorial as important as technical requirements that all together led to the changes of representation requirements. The second finding was obtained from the analysis of the 2 books on materials technology for ID and ED students. The intention of the ID and ED difference by authors were significantly represented. The third result was attained from the analyses and redesigns of the selected VTIs, which also had put in the questionnaire survey among 3 different countries in 3 regions that represent different cultural background, besides the cultural aspect between ID and ED education. These results were considered as reliable data because they could be used to compare and support each other.

Figure 7.24
Triangulation and Validation Study in Case Study-3
The book analysis provided evidence of differences of models and graphical strategies used in the VTIs for the ED and ID students (matched the claims and intentions of the authors). On the other hand, the VC principles applied on both books were not as effective as compared to the findings of the KEPs of VCT. Therefore, a second phase of study (the analyses and redesigns of existing VTIs from the 2 books and other sources for additional comparison and support) was conducted in order to gain further empirical evidence. The finding from these analyses and redesigns was extended to questionnaire survey for another stage of quantitative data. This was intended to obtain reliable empirical evidence for the whole Case Study-3. To further validate the triangulation findings, a discussion group was formed amongst materials experts in order to deliberate the triangulation results.
7.5 Summary of Key Findings

Table 7.19 summarises the key findings from the Case Study-3:

<table>
<thead>
<tr>
<th>Key Studies in Case Study-3</th>
<th>Key Findings</th>
<th>Validation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) ID vs. ED Materials Books Analysis</td>
<td>1. <strong>Lens-1</strong>: significant used of different types of model between ED book (more SYMBOLIC); whereas, ID book (more ICONIC) (Table 7.4 and 7.5).</td>
<td>The validation study from 3 experts of Materials reached the following outcomes: 1. Two of the experts’ views supported the literature review that the ID and ED students should have understand better VTIs that were presented in different styles of representational models, as well as the use of graphical strategies and techniques. This is due to their distinct nature of role they played. Whereas, 1 expert thought vice versa, where his views had supported the research evidence (section 7.3.4, Table 7.18).</td>
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<tr>
<td>(2) Diagrams Analyses, Redesigns and Questionnaire Survey</td>
<td>2. <strong>Lens-2</strong>: ED book confined to mainly use of SEQUENTIAL category of graphical strategy; whereas, ID book use various and mixture of graphical strategies to attain communication impact (Table 7.6 and 7.7).</td>
<td></td>
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<tr>
<td>(3) Experts Discussion</td>
<td>3. <strong>Lens-3</strong>: evidence of graphical application in both ED and ID books, but more in ED book (as having more statistical VTI); whereas, less in ID book (section 7.3.1: Lens-3 on the 2 chapters of the ED and ID books).</td>
<td></td>
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<td></td>
<td>4. <strong>Lens-4</strong>: evidence of the KEPs practice, but seemed to have space for further improvement (Table 7.8).</td>
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<td></td>
<td>1. Most of the redesigned VTIs (applied the criteria of KEPs) were more noticeable, understandable and more effective in communication as compared to the original, except for VTIs as in Figures 7.17 and 7.18, questions 2 and 3 that obtained slightly less in understanding (Tables 7.17).</td>
<td></td>
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<td>2. There was no difference in VCT for the ID and ED students, as well as for 3 different countries which are in 3 different regions (Tables 7.10-7.16). This means cultural differences do not affect VCT. However, there was little evidence of differences in level of study (educational background) in VCT (Tables 7.16; survey questions: 2, 5 and 6; Figures: 7.17, 7.20 and 7.21). A possible assumption: while reaching to higher education level, a more ABSTRACT form (less visual hints) of VCT was potentially understandable and preferred.</td>
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## Key Studies in Case Study-3

<table>
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<tr>
<th>(1) ID vs. ED Materials Books Analysis</th>
<th>(2) Diagrams Analyses, Redesigns and Questionnaire Survey</th>
<th>(3) Experts Discussion</th>
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### Key Findings

2. Two experts were surprised to see that a slight change in the redesigns could impact the effectiveness and understandable quality of VTIs; and that also ED students were more drawn to understand VTIs which were depicted with graphics clues (the redesigns). Whereas, 1 expert thought that the research findings were not to his surprise, because those graphics provided good visual associations, which connected to the real word situations. This aspect should help a younger people to understand the messages intended.

3. All 3 experts shared the same views of VTIs in relation to the cultural aspects; where they agreed that visual for technical purposes should be quite the same for all cultures as they should learnt quite similar content of technical. However, 2 of the experts did not consider the ID and ED as the context of culture within a community.

These can be referred to the results in sections 7.3.4, Table 7.18.

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**Table 7.19**

Summary of the key findings in Case Study-3
Chapter 8 Discussion

Chapter Overview

Chapter Eight discusses the outcomes from the three case studies in relation to the literature reviews and the contribution of the research in relation to the research objectives.

Figure 8.1 illustrates how Chapter Eight fits into the structure of this thesis.
The discussion in this chapter focuses on the three case studies initially, and then looks at the evidence they provide in relation to the research aim and objectives.

**PART I**

Discussion in this section is based on the literature reviews and the outcomes of the three case studies.

**8.1 The Links between VCT, Designing and Creativity**

**8.1.1 Literature review: VC, designing and creativity**

The literature review revealed that the use of visual communication (VC) has been significant since early human development of technologies. Alongside these technological developments, engineering education has evolved from taking visual aspects very seriously into account in the 1900s, but becoming less emphasised starting in the early 1980s (Ferguson, 1993). Recent research has also shown that there has been little emphasis of graphicacy and its place in education across curricula around the world at any level (Danos, 2009).

Nevertheless, academic research within these recent decades began to place greater and important emphasis on the area of VC across various disciplines. Amongst those disciplinary areas were: cognitive modelling and teaching and learning; cognitive modelling and designing; cognitive and computer sciences; as well as engineering and the historical analysis of technology. Along with these research areas, many claims of VC in relation to designing, creativity and innovation had also come into being. Some of the examples of those claims were:

- Imagery helps achieving higher levels of thinking within creativity and problem-solving (Curtiss, 1987; Codone, 2005).
- Visual mental images provide influential depictions for generating creative solutions to design problems (Finke and Slyton, 1988; Finke, 1989; Finke et al., 1992; Middleton 2005). Similarly, Ferguson (1993) emphasised that visual tools were the main elements used in communicating thoughts and stimulating meaningful relationships in order to develop new ideas in problems-solving and inventions.

- Inventors in engineering used both static and dynamic visual mental images in generating and testing new solutions to engineering problems (Weber and Perkin, 1989; Weber et al., 1990; Weber, 1992). This is also supported by the historian’s records of technology: the primary engineering information was recorded and transmitted in visual language, and has proven to help the thinker (designer/engineer) to expand their thinking and sensory experience – which is to convert the image in the mind's eye to usable visual information (Ferguson, 1993).

- Tacit knowledge via viewing and manipulating objects stimulates new ideas that help in the process of invention (Carlson and Gorman, 1992).

- “It is possible to speculate that technological representation in visual form facilitates cognitive modelling and its synthesis with aspects of form.” (Norman 1998, p.81)

- “The power of the visual image lies in the ease with which it can be manipulated by the mind and its ability to trigger creative thought.” (Ashby and Johnson 2004, p. 31)

- Design and technology learning is complex and requires higher-order thinking through visual mental imagery and manipulation of concrete materials in situations and contexts that are made meaningful to students for designing (Middleton, 2005).

- “The ‘dialogue’ in the mind between internal and external models provides a working space for creativity.” (Baynes 2009, p. 37)
Diagrams as an external visual representation can be used for spatial reasoning for problem-solving by abstracting spatial or non-spatial information from internal or external representations (Stieff, Hegarty and Dixon, 2010).

However, these were assertions without supporting empirical evidence from most of the research areas; or with little empirical evidence from those relating to cognitive and computer sciences area of research.

Creativity, on the other hand, as revealed by the literature review was known to be a complicated, very subjective and difficult concept to define and/or measure. This perspective of creativity was shared amongst Dewulf and Baillie (1999), NACCCE\(^1\) (1999), Dakers (2004), Spendlove (2005), etc. In fact, many researchers and educators have contributed to debates on this matter and there was no unique definition for creativity. Some definitions or associations of creativity are:

- It is always linked to ‘creative thinking’ or ‘ability’, ‘problem solving’, ‘imagination’ or ‘innovation’ (El Murad and West 2004, p. 189); and the creative ideas, according to them, “must be new, unique, and relevant to the product and to the target audience in order to be useful as solutions” (2004, p. 188).

- It is “something associated with new product” (Altiers 1988, p. 155).

- It is the ability to generate products (e.g. ideas, methods and forms) that are meaningful and uncommon to others (e.g. Sternberg and Lubart, 1999; Amabile, 1996; Gardner, 1989; Barron, 1969; Jackson and Messick, 1965).

- A creative idea is both ‘novel and useful’ (Martindale 1995, p. 250); however, he suggested, the novelty does not necessary exist from something totally new, instead it could emerge from the ‘new combinations of the old ideas’ (ibid, p. 250).

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\(^1\) National Advisory Committee on Creative and Cultural Education.
• It is ‘the disposition to make and to recognize valuable innovations’ by Laswells (cited in Gilchrist, 1972, p.10).

• It “can be defined as a feature of elitist high-level intelligence – innate and prominent in the gifted few and not considered as something that can be taught;” or it “can be recognised in all students to be facilitated and nurtured as an essential life skill, delivered across the school curriculum at all stages to restructure their own world and develop what Bandura (1995) refers to as ‘self-efficacy’.” (Spendlove 2005, p. 9)

The author of this thesis treated this overwhelmingly complex concept of creativity within Spendlove’s (2005) perspective of creativity in education as being the most relevant for this research. In particular, creativity “can be recognised in all students to be facilitated and nurtured as an essential life skill, delivered across the school curriculum at all stages to restructure their own world and develop what Bandura (1995) refers to as ‘self-efficacy’,” as mentioned above.

In addition to that view of creativity, an objective assessment of creativity should best be used and Thistlewood’s (1990) ‘archetypal’, ‘historicist’ and ‘evolutionary’ categories of designing were selected as providing a useful approach. This is because these categories are very effective ways of considering creativity within designing. Definitions of these categories are:

• ‘Archetypal’ are products which have developed through the generations and where “significant departure from these characteristics leads at best to less-fit artefacts and at worst ... to retrograde mutations” (Thistlewood 1990, pp. 14-15).

• ‘Historicist’ designing is where new examples do not supersede their predecessors because there is no essential form (Thistlewood 1990, pp. 14-15).
‘Evolutionary’ designing (Thistlewood 1990, pp. 15-16) obliges the designer to invent new forms that invalidate all their predecessors; e.g. electronic typesetting has invalidated hot metal.

The design level of archetypes was seen by the author as associated with little ‘c’ creativity; and the historicist level as related to big ‘C’ creativity (an approach used by Gardner, 1993; Simonton, 2000; and Craft, 2001 for the classification of creativity, as identified by Spendlove, 2005). Spendlove (2005) defined the creativity levels of little ‘c’ and big ‘C’ as follows:

- Little ‘c’ creativity is often used to indicate the ability of students to manage incremental change, problem-solving and the ability to adapt to change on a daily basis. Little ‘c’ creativity is likely to be a characteristic of designing artefactual products, or products that the designer regards as artefactual. Changes are likely to be restricted to altering factors such as colour, texture or the material, but the essential form will be retained (2005, p. 11).

- Big ‘C’ creativity happens when a creative solution to a problem establishes a ‘high novel’ response that shifts how other people think and live their lives (2005, p. 11).

8.1.2 Literature review: design and technology in education

The scope of technology in this research context was largely confined to the technology practice of Pacey’s (1983) ‘technology model’. His definition of technology practice consists of cultural, organisational and technical aspects (Pacey’s 1983, p. 6) as follows:

- **Cultural** – refers to goals, values and ethical codes, belief in progress, awareness and creativity.

- **Organisational** – relates to economic and industrial activity, professional activity, users and consumers, trade unions.

- **Technical** – concerns the knowledge, skills and technique; tools, machines, chemicals, liveware; resources, products and wastes.
Designing, on the other hand, is most primarily related to technology in terms of the technical aspects (Pacey 1983). Nonetheless, cultural issues such as values, and organisational aspects such as economic organisation, also have influence on designing. Norman (2008, p. 17) revealed that within designing processes, the technological boundary for designers is their knowledge, skills and values. Whereby, technology as the summation of ‘knowledge’, ‘skills’ and ‘values’ in design education was taken as the principle for analysing technological aspects and competencies for course contents and activities. Subsequently, the technological concepts within these competencies were assessed in the following manner. This theoretical position was based on the APU’s report by Hicks, et al. (1982).

- Control, Energy and Materials were categorised as the technological concepts for the ‘Knowledge’ competency (see section 2.1).

- Investigation, Invention, Implementation and Evaluation were categorised for the competency of ‘Skills’ (see section 2.1).

- Technical, Economic, Aesthetic and Moral were the 4 areas identified to assess the competency of ‘Values’ (see section 2.1).

These technological aspects were used in the next discussion section 8.1.4 in relation to Case Study-1 findings.

In relation to the kite-designing-task in CS1, all aspects of ‘knowledge’ i.e. Control, Energy and Materials categories are significant, because they are the key factors for kite-making and -flying. Control would link to the aspect of making; energy would be the concern of forces on the kite while flying; and materials would be a key component for building the kite. However, the studied subject: the kite-VTI was designed without materials information. Therefore, the materials aspect of technological knowledge will be not considered for further discussion.
In terms of ‘skills’, the categories of ‘Investigation’, ‘Invention’, ‘Implementation’ and ‘Evaluation’ are all significant in kite-designing, as they relate to the identification and solving of design-problems (Investigation); developing and illustrating ideas, making and creating (Invention); ability to select and make decisions (Implementation); and lastly methods and resolutions to judgement (Evaluation).

In terms of ‘values’ in relation to kite-designing, Technical and Aesthetic categories are likely to be the most significant, because they relate to the determination of form and strategies for implementation.

### 8.1.3 Case Study-1: VCT > Designing > Creativity

Case Study-1 (CS1) was designed to have 3 stages as follows:

- Accessing information about kite’s structures, kite-making and kite-flying.
- Students’ kite-designing workshop.
- Assessment and analysis of creativity within the outcomes of students’ kite-design.

The information about kite’s structures, kite-making and kite-flying which were provided during the CS1 activity, included: actual kites; materials for kite-making; kite posters; and web links on kite-making and -flying. The existing kites were displayed to provide actual visual and structural samples. These were provided with the intention of later tracing, whether any kite-design outcomes from the students would fall into the category of just copying the existing kites that were available to them. Materials for kite-making provided the opportunity for students to explore not only potential materials from which to make kites, but also the opportunity to experience the investigation of properties and the sensorial feel of materials, which might lead to potential for creativity and experimental outcomes. Kite posters (a form of kite-visual-technological-information/kite-VTI) played the role of visual communication of technology, and that was the investigation subject of CS1 to track possible links of VC, designing and creativity.
Finally, web links were known to be a common modern tool for information searching which might be important for some students and which students might find it surprising to be without.

The kite-designing task as described for CS1 was selected as a possible empirical method for tracking the complex chain of those claims – VC, designing, creativity and innovation within a simple designing task. In fact, kite-designing, particularly the miniature-kite-designing in CS1, can be seen to be simple in the sense that the task was on a small-scale and it could be completed within an hour or even less. However, making a unique kite and making it fly involved several aspects of the technological knowledge behind the designing.

These technological aspects include structural design, materials and the mechanics of kite flying, which include aspects of fluid dynamics, analytical mechanics, material properties and strength analysis, and meteorology according to Ito and Komura (1983). In addition, technological aspects were likely to be important for kite-making because according to the experts, “In order to be creative, it is essential to know how things work. The more the range of creation extends, the more it is necessary to understand most basic tenants,” (Ito and Komura 1983, p. 12). Thus, there is the potential for greater understanding of the technology behind the kite-making leading to more creative outcomes. These more creative outcomes would be demonstrated through more ambitious and innovative kite forms. This distinction between replication and novel forms provided the opportunity for an appropriate empirical measure of creativity.

The characteristics of either retaining an existing form or changing that form provide a framework for an objective assessment of the creativity embodied in the students’ kite-designs. The creativity assessment criteria that were adopted and applied in judging the students’ kites were the following:
1. Those kites that were not copying the existing kites made available to the students, common kites available in the market or those that had been displayed in the museums were judged to be ‘Historicist’ designing with big ‘C’ creativity.

2. Those kites where the structure and shape seemed inherited from those of existing kites, but with slight changes in details e.g. the fin assembled a pair of hands to the Mr. Potato-head-kite or the tail of a diamond-kite was added with colourful stars etc. These types of inherited forms of kites would be considered as ‘archetypal’ designing with little ‘c’ creativity.

3. The ultimate judgement of creativity and innovation (if there is any) would be of totally new forms or structures for kites, which would be regarded as representing ‘evolutionary’ designing.

However, the author’s view would be that in the case of kite-designing, it would be difficult to reach to the extent of the ‘evolutionary’ category of designing. Given the concept that ‘any shaped kite can make to fly’, the structure of a new design form would never invalidate all the other existing kites in respect of some criteria. An evolutionary kite-design would be more likely against a tighter specification, such as a particular performance criterion for function, e.g. speed or height, but that was not a feature of this case study.

The tracking of the chain of the links began from accessing various sources of kite-technological-information, through the kite-designing task given to students, through the assessment of creativity, and ended with a questionnaire survey (which gathered information on which kite information sources helped to solve the kite-making and kite-flying problems, and where inspiration for the kite-design ideas originated).
8.1.4 The findings for links: between VC, designing and creativity

Within the triangulation of CS1, literature review was the first strategy to be explored and had found the assertions of the links between VC, designing, creativity and innovation; and revealed the complexity of the concept of creativity as mentioned earlier in section 8.1.1. The second strategy was the miniature-kite-designing-task given to ID students in LDS, UK; and the third strategy was a comparative study conducted in PJB, Malaysia amongst ID and ED students.

These two comparative studies, the miniature-kite-designing between the UK and Malaysia, had established the following findings.

- VCT contributes to ‘knowledge’ gained in terms of Control and Energy of the technological concepts as referred to by Hicks et al. (1982). Evidence obtained: Most UK students stated that kite-VTI was the most significant source of information (Tables 5.8 and 5.9, Chapter 5); and a large numbers of the Malaysian students stated it had some significance to their knowledge gain (Tables 5.10 and 5.11) within the following positions:
  - From the kite-VTI/posters, they obtained knowledge of ‘any shaped kite can make to fly’ as long as there was proper attachment of the bridle based on the centre of gravity, and understood the ideas for balancing of kites (item 4(ii) in Table 5.9; and item 3(ii) in Table 5.11). These were linked to the Control aspects of ‘knowledge’ as they managed to understand how the kite structures worked, and applied these concepts.
  - From the kite-VTI, they comprehended the information of forces and how a kite flies, and learnt the importance of lift in keeping the kite airborne (item 4(ii) in Table 5.9; and item 3(ii) in Table 5.11). This was about the sources of Energy in the ‘knowledge’ aspect of technology as they were managed to understand how the mechanics of kite flying worked, and applied these concepts.
[Note: The Materials aspect of ‘knowledge’ was not embedded in the kite-VTI, thus none of this aspect was mentioned by the users of this kite-VTI, and hence it could not be measured.]

- ‘Skills’, as in all 4 aspects of Investigation, Invention Implementation and Evaluation, can be communicated through the VCT. The evidence obtained was:
  
  - The student participants demonstrated the ability of designing their own shaped kite without copying existing kites or those kites that were available for them during the kite-designing-task (Table 5.5). Through the designerly thinking and activity (as they reported that they had solved the kite-flying problems and instability by referring back to the kite-VTI, item no. 2, Tables 5.9 and 5.11), the majority of the participants resolved the problems and produced their own final kites which flew. These included 24 out of 28 kites from the UK group; 7 out of 12 ID’s kites, and 5 out of 6 ED’s kites of the Malaysian group that could fly (Table 5.5). These results showed that they managed to identify the kite-design problems and solved the problem by using the kite-VTI (as 2/3 of the 145 UK participants, Table 5.8; and 3/4 of Malaysian ID and 2/3 of 24 ED participants, Table 5.10 described that they initially faced problems in making the kites fly). These processes were about the Investigation aspects of the competency of ‘skills’.

  - During the kite-designing-task, all the student participants did sketches and planned their kites with annotated drawings during the developments of kite-design ideas and discussion amongst their teams (Figure 5.3); making and creating their kites (Figure 5.7) until completion of the final product. Most importantly, the participants highlighted that they got inspiration and ideas for kite-design from investigating through the kite-VTI (which was the most significant impact of information source for inspiration, Tables 5.8 to 5.11).
Hence the VTIs support the *Invention* aspect of designerly ‘skills’: abilities in initiating and developing ideas and illustrating those ideas via drawing and making, creating alternative resolutions.

- From the sketches/drawings of ideas and discussion amongst the group members (Figure 5.3), the students demonstrated the ability of selecting the final kite-design to represent their groups. They also achieved the requirements from the kite-design briefs that had different specifications of themes to be reached for the UK and Malaysian groups (Appendices 5.1 and 5.3 for the design briefs). Hence the VTIs can be traced as having also contributed to the performance of the *Implementation* aspect of ‘skills’.

- The majority of the participants (both from the UK and Malaysia) used the kite-VTI for guidance and inspiration, and solutions for their kite-design problems, as indicated by the evidence for the above 3 aspects (*investigation, invention* and *implementation*) of skills. Hence it could be implied that there was also some sort of system or methods used by the students, who referred back to the kite-VTI for troubleshooting of kite-flying and kite-instability, managed to couple this with the ability to see which of the proposed resolutions to the kite-design could be judged to be likely to be applied successfully to their own kites in making them fly. This was assumed because most of them managed to solve the problems by the time of the submission of their kites. Evidence for these aspects was the same as for the above 3 characteristic (Tables 5.8 to 5.11). These processes were about the *Evaluation* aspects of the competency of ‘skills’.
There are suggestions of the communication of ‘values’ through VCT. The areas of ‘value’ implied were the Technical and Aesthetic aspects. Evidence obtained:

- Most of the student-groups demonstrated the expressions of perception of forms and colours that communicated ideas, meanings, and/or expressions by designing their kite with inspirations from the kite-VTI (Tables 5.8 to 5.11). They also applied those expressions in designing their kites according to the design themes as stated in the design briefs, and named their kites to match the themes. These were about the Aesthetic aspect of ‘values’.

- They learnt that ‘any shaped kite can fly’ from the kite-VTI (as they reported, see Tables 5.9 and 5.11) and therefore, they did not confine themselves to traditional or existing kite forms and shapes, rather the kite-design could just take any form and shape as they explored. This showed that they had applied the understanding of the technology behind the kite-design, and that they demonstrated some efficiency, flexibility, precision and confidence in experimenting with new form of kites in their designs. These were about the Technical aspect of ‘values’.

However, the percentage of respondents who found significance in the aspect of ‘any shaped kite can fly’, and which inspired the kite ideas amongst the participants from Malaysia was not as high as compared to the UK percentage. This could be caused by the different format of kite-VTI used for these 2 groups during the kite-designing-task.

[Note: Other aspects of ‘values’ such as Economic and Moral were not evidence in this CS1 kite-designing. Therefore it was impossible for the participants to design kites related to those aspects; or to learn from the kite-VTI about the values of price and cost (the Economic aspect), or having awareness to the natural environment (the Moral aspect) in their kite designs.]
Students’ kites displayed creative and innovative responses when analysed in relation to Thistlewood’s (1990) historicist and archetypal categories of designing (Tables 5.5, 5.6 and 5.7). This analysis was not as easy as the kite-design outcomes simply falling into either of the historicist or archetypal categories, as some of the kites had characteristic that could be considered to belong to both categories. However, it did prove to be possible to reach overall judgements concerning the category into which each design should be put, as shown in Appendix 5.2 and Tables 5.5, 5.6 and 5.7. None of the students’ kites were identical with the existing kites, and none fell in the category of ‘evolutionary’, as anticipated.

Those students’ kites that were grouped in the category of archetypal/little ‘c’ creativity possessed the following criteria:

- The main structures and shapes of the kites were assembled or inherited from other existing kites, but the detailed elements of the kites such as colours or combinations of colours, textures or decorations on kites, materials used, tails and fins attached were creatively manipulated and thus not identical to the existing designs.

[Note: These details matched the definition indicated by Thistlewood (1990) about archetypal: “significant departure from these characteristics leads at best to less-fit artefacts and at worst... to retrograde mutations” (1990, pp. 14-15); and those criteria by Spendlove’s (2005): where changes are likely to be restricted to altering factors such as of colour, texture or the material, but the essential form will be retained (section 8.1.1).]
Whereas, those students’ kites that were grouped in the category of historicist/big ‘C’ creativity possessed these criteria:

- These kites were not identical to nor copying from the existing kites, instead they were new designs, where the shapes, forms or structures of the kites were slightly altered (although their origins could be recognised) to become their own unique forms of kites.

[Note: These criteria corresponded to the definition of Thistlewood’s (1990) historicist designing: where new examples do not supersede their predecessors because there is no essential form; and as Spendlove (2005) emphasised: when a creative solution to a problem establishes a ‘high novel’ response that shifts how other people think of it (section 8.1.1).]

- There was also an interesting finding in terms of creativity related to the different groups of ID and ED students’ kite designs. The evidence showed the following results (also shown in Table 5.5):

  - The kite-design outcomes from the ID groups (both the UK and Malaysia) consisted of both big ‘C’ and little ‘c’ creativities.

  - All the kite-design outcomes from the ED groups (only the Malaysian samples, there was no UK samples during the CS1) consisted of only the little ‘c’ creativity.

Hence, the evidence so far showed that the differences in the ID and ED participants were only in the kite-design outcomes. The approaches of these 2 groups of students toward the kite-VTI and the kite-designing-task were very similar. However, there were some contradictory findings in the ED participants’ perception towards the kite-VTI. On the one hand, the kite-VTI was identified as the significant source that helped to overcome the kite-flying problems (item 2(ii) in Table 5.11). On the other hand, they stated that the kite-VTI was not helpful (item 3(i) in Table 5.11).
In this case, the author decided to choose the first perception as closer to the true scenario. This decision was based on the questions 2(i) and 3(ii) which had been asked, and the findings related to those questions were:

*Question 2(i): Did you have difficulties getting the kite to fly?* The answers showed 67% of the ED group faced difficulties in getting their kites to fly (see Table 5.11). Followed by *Question 2(ii): If yes, what sources of information helped you to overcome the problem?* The answers were: 17% of them pointed to the kite-VTI as the most significant source, but none of them acknowledged that the internet source was the most significant; 33% considered that the kite-VTI had some significance to them, with a similar result for the internet source (Table 5.11).

However, in the real scenario, where this ED group were in the process of modelling their kites and faced the flying problems, the internet service was down; and that means they actually only referred to the kite-VTI, as observed by the author. The answers that pointed to the internet were hence assumed by the author to be just an ideal source if they could have had it at that time; or that was the ED students’ perceptions towards these 2 sources, where they did not value the VTI as highly as the ID group did.

*Question 3(i): Did you find the information posters about kites helpful?* 67% of the ED participants answered ‘No’ (Table 5.11). Followed by, *Question 3(ii): If yes, describe how they were useful.* Only 1 of the participants answered this section.

These responses suggested that the participants were not so willing to respond, and were trying to avoid answering the question with written words. This could be just the author’s assumption, but these 2 answers were obviously contradictory to the previous 2 responses. Whereas, the answers given to questions 2(i) and (ii) felt more like spontaneous and genuine responses as compared to those in questions 3(i) and (ii).
The overall findings within the triangulation of CS1 showed that the kite-VTI works to communicate some aspects of knowledge, skills and values, although there is not evidence for all of the aspects as discussed above. This picture of association can be made clearer by putting all the pieces into one event: Knowledge (delivered through the kite-VTI) had provided references and guidelines to the kite-designing processes (which were referred to the designerly performance of skills), and the kite-VTI was also able to stir up some inspirations and made some impact in changing of views of students, this contributed to some small changes in aspects of values. Consequently, this empirical evidence from CS1 revealed that the VCT does have links to designing and facilitates creativity and innovation.

8.1.5 **Validity of the triangulation in CS1**

The above findings were further validated through another phase of the kite-designing study (Phase-6 of the CS1), which was tested amongst the PGCE trainees; the participants coming from LDS, UK. The miniature-kite-designing-task and the creativity assessment were the same as the previous 2 comparatives studies. The change in this validation study was about the information provided concerning the kites, which was only the kite-VTI. This decision to change was made because the previous 2 studies revealed the most significant source of information was the kite-VTI. Thus, it was seen appropriate to validate its use in isolation as the only source for kite-technological-information, in order to check the validity of the triangulation evidence concerning how the VTI works and the link between VCT, designing and creativity.

The validation task had similar outcomes to the previous 2 studies as follows:

- **Kite-VTI was acknowledged as very informative and helpful visual information in providing basic technological knowledge about the kite-making amongst all the participants (section 5.3.4, and the evidence of how informative and helpful the kite-VTI was in Table 5.14).**
- The kite-VTI had inspired them in generating ideas for kite models and helped them in making the kites, particularly about the troubleshooting of balancing and instability problems that they encountered during the kite-designing-task (section 5.3.4, and the evidence of what they had perceived from the kite-VTI were shown in Table 5.14). The troubleshooting sections in the kite-VTI helped them solve the flying and instability problems, and for this validation group all kites could fly at the end of the project (Table 5.13).

These 2 findings confirmed the evidence obtained in the previous 2 comparative studies that the kite-VTI comprised and was capable of delivering technological knowledge for kites in terms of the structural aspect of the kite-making, the fluid dynamics aspect of the kite-flying, and contributing in the kite-design inspiration (discussed in section 8.1.4). These were closely linked to VCT having played a role in imparting knowledge, skills and values as found in the previous 2 comparative studies.

- Assessment of creativity in the validation group also showed responses of little ‘c’ and big ‘C’ creativity in kites (Table 5.13 and Appendix 5.1). The criteria of the final kites, which possessed the little ‘c’ and big ‘C’ categories were the same as those creativity criteria discussed in section 8.1.4 for the 2 main studies of the triangulation in CS1.

Thus, this result confirmed the evidence of creativity obtained in the earlier 2 comparative studies.
As a consequence, the overall results from these 3 studies in CS1 showed that the kite-VTI was effective, and hence the link between visual communications of technology (VCT) to modelling in designing and facilitating creativity and innovation were supported. This evidence also provided empirical data to support some of the claims that have been asserted in the literature. These include:

- Visual mental images provide influential depictions for generating creative solutions to design problems (Finke and Slyton, 1988; Finke, 1989; Finke et al., 1992; Middleton 2005). This can be related to the empirical data concerning ‘skills’ (within the aspects of *Investigation* and *Implementation*) communicated through VTI [NB: VTI > Skills (*Investigation* & *Implementation*)]. However, the same VTI > Skills empirical evidence could also partially support the assertion: Inventors in engineering used both static and dynamic visual mental images in generating and testing new solutions to engineering problems (Weber and Perkin, 1989; Weber at al., 1990; Weber, 1992). This is because the author considered the VTI used in the investigation belonged to only the static visual category, and is not clearly a dynamic visual.

- Tacit knowledge via viewing and manipulating objects stimulates new ideas that help in the process of invention (Carlson and Gorman, 1992) would be relevant to the empirical data indicating that the VTI contributed to ‘knowledge’ in terms of *Control* and *Energy*; and ‘skills’ within the aspects of *Investigation* and *Invention* gained [NB: VTI > Knowledge (*Control* & *Energy*) > Skills (*Investigation* & *Invention*)].

- “It is possible to speculate that technological representation in visual form facilitates cognitive modelling and its synthesis with aspects of form.” (Norman 1998, p.81) would be supported by empirical data of the VTI contributing to technological aspects of ‘knowledge’, ‘skills’ and ‘values’ [NB: VTI > Knowledge, Skills, Values (cognitive modelling activities)].
• “The power of the visual image lies in the ease with which it can be manipulated by the mind and its ability to trigger creative thought.” (Ashby and Johnson 2004, p. 31). This can be best matched to the empirical evidence of VTI contributing to ‘values’ gained in the areas of Technical and Aesthetic [NB: VTI > Values (Technical & Aesthetic)].

• “The ‘dialogue’ in the mind between internal and external models provides a working space for creativity.” (Baynes 2009, p. 37) can be supported by empirical findings related to the linking of the VCT and designerly activities, and thus it facilitated creativity [NB: VCT > Designerly Activities (involved knowledge, skills and values) > Creativity].

• Diagrams as an external visual representation can be used for spatial reasoning for problem-solving by abstracting spatial or non-spatial information from internal or external representations (Stieff, Hegarty and Dixon, 2010). This can be supported by empirical data from these research findings, where ‘knowledge’ and ‘skills’ can be communicated through VTI [NB: VTI > Knowledge & Skills].

However, the empirical data in CS1 only partially supported the following 2 assertions, in terms of image (VTI) contributing to knowledge and skills for these 2 cases:

• Imagery helps achieving higher levels of thinking within creativity and problem-solving (Curtiss, 1987; Codone, 2005); and

• Design and technology learning is complex and requires higher-order thinking through visual mental imagery and manipulation of concrete materials in situations and contexts that are made meaningful to students for designing (Middleton, 2005).

This is because the evidence obtained could not support the aspect of ‘higher level or order of thinking’ as the case study did not have any features that measured the aspect of thinking level.
The empirical data, in fact, were not very surprising, because the findings from the historical records by Ferguson (1993), also provided such connection, e.g. the primary engineering information was recorded and transmitted in visual language, and has proven to help the thinker (designer/engineer) to expand their thinking and sensory experience – which is to convert the image in the mind's eye to usable visual information. Also, the visual tools were the main elements used in communicating thoughts and stimulating meaningful relationships in order to develop new ideas in problems-solving and inventions (Ferguson, 1993).

Nevertheless, this study by using this particular kite-designing method enabled empirical evidence to be obtained, and contributed to our general understanding in regards to the visual communication of technology. Consequently, the VCT could be used as delivery tool for instilling technological knowledge, skills and values of technology, as discussed in 8.1.4.

8.2 The KEPs of VCT

8.2.1 Literature review: visual communication principles and languages

The literature review disclosed that there were many good examples of principles and techniques for design in various areas of design fields. Within these areas, there were general visual language and graphics principles (Rand, 1971; 1985; Malamed, 2009), data graphics (Tufte, 1983; 1990; 2004), general design (Tufte, 1983; Shadrin, 1992; Rawland, 1993), message design (Pettersson, 1993; 1997; 2010; Wileman, 1993), instructional design (Lohr, 2003; Smith and Ragan, 1999; 2005), instructional message design (Fleming and Levie, 1993), information design (Lipton, 2007; Pettersson, 2002; 2007), and graphics principles for engineering drawings (Thomson, 1979). However, these principles were either broad and general or very specific in providing perspectives for those design areas, and there were none that were specifically meant for the design of technological visual information.
Consequently from the literature review and within different areas of expertise, the key emerging principles of visual communication of technology (KEPs of VCT) were developed. The disciplines areas that provided the main references for the developments of the KEPs included the following areas:

- Data graphics principles and techniques from Tufte (1990; 2004; 2006), particularly looking for the quantitative and statistical graphical visual information design aspects.
- Visual communication and graphics principles from Rand (1971; 1985), mainly aimed at the persuasive aspect of graphics language.
- Graphics principles for engineering from Thomson (1979), which represented the principles applied in engineering drawings.
- Historical evidence of technology in relation to the mind’s eye from Ferguson (1993). This was particularly exploring the history of engineering design and its related effective visualisation tools as used in past successful practice.

The KEPs that emerged from the above studies were:

- **KEP-1**: Facilitating *Comparison* to reveal *Connection* and *Relationship*
- **KEP-2**: Unity of *Form* to accentuate *Function*
- **KEP-3**: *Precision* of data to communicate *Accuracy* and inform the *Truth* (meaning, message, dimension etc.)
- **KEP-4**: *Simple* in design form; *Complex* in carrying data or information

These KEPs of VCT were adopted as the foundations for a theory which would be tested within further investigations planned for Case Study-2 (CS2). CS2 was designed to examine how the VCT works within the links of VC, designing and creativity.
Also, useful visual design language and guidelines for the structuring of visual representations had been provided by Kress and van Leeuwen (1999), Engelhardt (2006), as well as Malamed (2009). Within this broader perspective concerning the overall strategies for the structure of representations, Kress and van Leeuwen’s (1999) works were explored initially. The aspects that needed to be taken into consideration for the VTI-design were as follows:

- VTI-design should be considered to be under the category of analytic visual. The analytical structure of its representation should be like a map that has both Carrier and Possessive Attributes, which can be turned into a blueprint at any time (as analysed by Kress and van Leeuwen, 1999). This also meant that this type of representation is already very specific and précised for final mass usage. Not like a painting, where it could have either Possessive Attributes or be a Carrier, and could leave spaces for readers to interpret to form their own consensus (Kress and van Leeuwen, 1999).

- Within the analytical structure, the use of structured descriptors processes (Kress and van Leeuwen, 1999) was seen as appropriate for technical and technological visual representations. The relevant descriptors might be: *temporal analytical process* (which is about a timeline); *exhaustive analytical process* (which is about showing all parts from which the whole is made up); *dimensional topographical accuracy* (which is about the process of drawing to scale); *quantitative topographical accuracy* (which is about representing the number or parts); and *topological accuracy* (which is about representing interconnection accurately) (Kress and van Leeuwen 1999, pp.107-108).

- Other components that were quite appropriate for technological information design were related to images that possess ‘objective attitude’. These included visual elements that represented *action orientation* (an exact one view), and *knowledge orientation* (from several different points of views) (Kress and van Leeuwen, 1999).
In terms of layout and arranging graphic or visual elements within the VTIs, objects, spaces and properties – the visuals syntax terminology of Engelhardt (2006) would be taken into account and applied. However, this should be at a stage after the representational structure had been identified. Based on Engelhardt’s (2006) terminology, aspects which might be applicable to VTI-design are:

- **‘Objects’** (any element that is used on the visual representations) may have different syntactic functions; where the syntactic functions of objects are referring to: node, connector, frame and label.

- The placement of these objects would be like playing around with **‘spaces’** on a plane or surface, a ‘building block’ for objects and sub-objects as defined by Engelhardt (2006).

- Additionally, to make the visual representations become more meaningful, **‘properties’** such as colours or sizes would be applied so as to complement the overall graphics objects.

Besides, graphics and visual language principles offered by Malamed (2009) which could be considered in CS2 were within the aspects of:

- **directing the eyes** by guiding the viewer’s eyes through the structure of a graphic;

- **reducing realism** by reducing the realistic qualities embedded in a graphic;

- **making the abstract concrete** to support understanding of the world and communicating about it; and

- **clarifying complexity** because information is complex when it is voluminous, dense, and lacking in structure.

However, the principles of reduce realism, and make the abstract concrete might be less relevant; although they might be more significant for the later discussion of CS3. Malamed’s other 2 principles: organise for perception, and charge it up were not applicable in these case studies.
8.2.2 **Case Study-2: KEPS of VCT**

Having established links between VC, designing and creativity in CS1, the next matter for research was whether the KEPS as applied in the kite-VTI had been used to enhance the communication of kite technology effectively. The further investigations needed in order to validate the KEPS required in-depth investigations of the researcher’s practice.

The analysis of successful visuals used currently and in the past practice was decided to be an important strategy for analysing any similar key principles behind the design of those successful representations. The eye-tracking device which enabled the capture of real eye-movements while reading visuals was believed to be an effective strategy for obtaining scientifically-based evidence.

As a consequence, Case Study-2 (CS2) was planned to investigate and articulate the criteria for the KEPS of VCT when taken out of a specific context, initially in 2 phases of study, as follows:

- Design and redesign of the kite-VTI applying the KEPS.
- Analysis of the reading patterns of kite-VTI using an eye-tracking device in order to investigate the KEPS.

**PHASE-1 of CS2: Design and redesign of kite-poster**

Within this CS2, the author’s own expertise in graphic design was used to design and redesign the kite-VTIs, applying the KEPS. Two posters of kite-technological-information (Figures 4.5 and 4.6) were initially produced for use in CS1, and obtained evidence of positive impacts as the most preferred sources for problem-solving in the first kite-designing workshop in the UK. The design criteria and intentions for the kite-poster were as follows:
• The overall structure of the kite-poster-design consisted of ‘whole’ and ‘parts’ (Carrier and Possessive Attribute, as termed by Kress and van Leeuwen, 1999). The red kite-poster, to represent the idea of ‘whole’, was about 4 basic types of kite structures with the title, ‘Any shaped kite can fly!’ The cyan kite-poster, to depict the idea of ‘parts’, was detailed with kites’ performance and troubleshooting. These technological details included the aspects of forces acting on the kite while flying and balancing the kite by finding the centre of gravity (for performance); and troubleshooting in terms of kite-flying and instability. The overall image of these 2 posters possessed ‘objective attitude’, where the red-poster was action-oriented; and the cyan-poster was knowledge-oriented, based on interactive meaning in images as described by Kress and van Leeuwen (1999).

• The objects and sub-objects of the graphics and visual elements of kites were arranged in quadrant-sections in the spaces of the 2 posters. This was done with the intention of implying ‘symmetrical balance works best’ (KEP-2: about Form that accentuates Function). It was also about the application of the KEP-1 for the purpose of Comparing and making Connections and Relationships; and KEP-4 for Simplicity in form and carrying Complex information about kites. [NB: for detailed elaborations of the application of KEPs see section 4.1.1, Chapter 4]

The properties applied were in terms of colours and various sizes of graphics elements and text (text includes: title, sub-title, annotations and annotations’ guides: lines and arrows). These properties were further emphasised by KEP-3: Precise in data to communicate Accuracy and inform the Truth. [NB: The discussion was related to Engelhardt’s (2006) terminology of visual syntax]
• The application of KEP-1 also matched the idea of ‘direct the eyes’ by guiding the viewer’s eyes through the structure of a graphic (Malamed’s principles, 2009); therefore, able to *Compare*, make *Connections* and building up *Relationships* for better decoding of messages.

• The application of KEP-4 matched Malamed’s (2009) principle of ‘clarify complexity’ (because information is complex when it is voluminous, dense, and lacking in structure). The structure of the representation was designed to obtain a simple form, and the information about technology for kites, of course, was complex. [NB: KEP-4: *Simple* in design form, *Complex* in carrying data, precise elaborations of the application of all the KEPs see section 4.1.1]

The second version of the kite-poster was restructured in an A3 size format of a questionnaire; where the kite-VTI stands within an A4 size with the related questions opposite. This was done due to the suitability in handling the survey documents for overseas purposes – travelling to Malaysia. The kite-information was carefully restructured by keeping almost all the visual representations of the existing kite-technological-information from the 2 posters. The visuals and information from the cyan-poster was retained in exactly the same form, except for the change in the presentation format. The photographic images of kites were the only elements that were taken out from the red-poster, but the illustrated kite samples were retained. An obvious difference between the 2 kite posters and the reformatted version was in terms of colour. The initial 2 posters were presented with one in red (depicting ‘Any shaped kite can fly!’) and the other was in cyan (depicting all the technological details). However, the reformatted version was mainly in cyan colour with the title of ‘Any shaped kite can fly!’ in red.

This change of colour feature during the reformatting was suspected of having made a difference in the outcomes of responses between the participants from the UK and Malaysia in CS1. This was because the result of ‘Any shaped kite can fly!’ in inspiring kite ideas obtained from the Malaysian groups showed a lesser percentage of significance as compared to the UK group.
As a consequence, the kite-poster and the reformatted kite-VTI embedded in the questionnaire were again analysed in parallel with the successful past practice visual by Leonardo da Vinci (Figure 4.9). The findings ultimately pointed to the effectiveness of the concept of ‘whole’ and ‘parts’ (Kress and van Leeuwen, 1999), which provided good objects and sub-objects (Engelhardt, 2006) for comparison, and hence provided opportunity for making connections and relationships (the author’s KEP-1, Beh and Norman, 2009). These were about the strategies for ‘directing the eyes’ (Malamed, 2009) of viewers to see what was intended, and hence could successfully decode messages embedded in the visual representations.

All these aspects were embedded in the first version of the 2 kite posters, but were missed out from the second version of kite-VTI. Therefore, the third version of the kite-VTI (as in Figure 4.8) evolved, where the red-poster that functioned as a ‘whole’ and which also carried the essence of ‘Any shaped kite can fly!’ – An essential feature was put back in the kite-VTI. This version was then used for the analysis together with the selected visual of the past practice in the main study.

**PHASE-2 of CS2: Eye-tracking investigation of the redesigned kite-VTI in comparison to da Vinci’s drawing**

The new evolved version of kite-VTI, which was improved through feedback from a number of studies (including CS1, pilot test and initial eye-tracking exercises on kite-poster, and re-evaluation using the criteria of KEPs), was used for further investigation in order to gather corroborative evidence for the reliability of the data gathered for the KEPs’ criteria. This investigation was conducted through using mixed-methods of eye-tracking, conventional protocol transcripts, and a comparative analysis with the effective past visual (da Vinci’s drawing, 1500) that was identified as having possessed similar applications of visual emphasis and KEP categories.
The assessment approach that first tracked the participants’ eye reading patterns, perceptions and understanding of the 2 visuals without language assistance, later with language and with prompting questions as guidance, and finally looked for similarity was helpful in obtaining objective data that tracked the KEP-3 applied. This data led to the need to search for more evidence for the remainder of the KEP categories. Consequently, the analysis of other visuals from the past and current practice that possessed KEP-1 and KEP-2 was decided to be necessary to validate this evidence from this first study of KEP-3. Therefore, it was decided that this should become the validation study for CS2. KEP-4 was not considered in this investigation because the author made the assumption that most of the visuals, which possessed good impact of visual representations and/or emphases, usually applied KEP-4: SIMPLE in design form, with carrying COMPLEX data. These aspects are discussed further in relation to the validation findings/results of the case studies.

8.2.3 The findings of the workability of KEPs

Within the triangulation of CS2, literature review was first explored and the KEPs emerged as a hypothesis for further investigations, as stated earlier in section 8.2. The second approach was the kite-poster design and redesign; and the third strategy was using the eye-tracking on the kite-poster to validate the KEPs. In particular, about the participants’ responses as to whether it provided any key features that related to the KEPs. These studies of kite-poster design and the eye-tracking using it had established the following findings.

- KEPs-1, -2 and -3 applied in the kite-poster design could be tracked directly by the participants’ reading patterns (eye-scanning paths) captured by the eye-tracker device on the visuals, together with the participants’ corroboration by describing features that related to how and what had been perceived from the poster, e.g.:
While the participants read the AOIs 1 and 2, they mentioned that they knew something about the kite-lift and the facts of wind-force on kites, but were not quite sure how to do it (section 6.4.1; Tables 6.5 or 6.6). When they moved on to reading the AOIs 3 and 4, they said they learnt the techniques and solutions to make a kite stable under the lift forces.

[NB: The design intention for AOIs 1 and 2 were about clues and provoking interest to find out more; whereas, AOIs 3 and 4 were about ‘how-to-do’ aspects. These were described in detail in section 4.2.1 (item number 2), Chapter 4.]

These findings showed that the FORM or structure of the kite-poster FUNCTIONed, in terms of its capability to guide viewer to navigate the information within the poster. This corresponded to the KEP-2: Unity of FORM to accentuate FUNCTION.

In either reading the AOIs from AOI-1 > AOI-2 > AOI-3 > AOI-4; or AOI-1 > AOI-3 > AOI-2 > AOI-4, the participants understood the poster the same way (section 6.4.1; Tables 6.5 or 6.6). The key aspects that the participants described were about their actions of comparing the visual elements depicted in those AOIs. Also, they could connect the forces on the kite that affected kite-lift, with techniques and solutions which could be applied to solve the kite-flying and instability problems. These mentioned features were all about comparing visual elements, making connections and building up relationships amongst those elements to achieve understanding. This matched the KEP-1: Facilitating COMPARISON to reveal CONNECTIONS and RELATIONSHIPS.

All 3 participants could describe the details of how to make a kite to fly and resolutions for the troubleshooting for flying and instability. This implied that the poster achieved the KEP-3, by having PRECISION of data to communicate or inform the TRUTH.
• KEP-4 (SIMPLE in design form; COMPLEX in carrying data), in this study, was unable to be directly tracked because it was not directly mentioned nor did those features mentioned directly link to KEP-4. However, an assumption of evidence to support the existence of KEP-4 and its workability could be made (author’s view), based on the record that all 3 participants only spent a very small amount of time in comprehending the poster (although not all messages), and were able to describe detailed features about techniques to make a kite fly, and mention additional solutions when facing instability or lift issues from the poster. All this complex information could have been difficult to capture and understand, if they were presented in a complex manner. A complex way of presenting this information would presumably have led to a longer time being taken to comprehend the messages. Thus, it can be argued that all the complex information was presented in a simple form, which eased the process of reading and understanding.

8.2.4 Validity of the triangulation in CS2

The findings from the 2 studies were further validated through analysing visual representations used in the past and within current practice. The strategy was to identify their strengths in terms of design quality, and whether they have any connections to the KEPS established from the literature review.

The past practice of good visual representations in communicating technology from the 16th Century was identified from Ferguson (1993) in relation to the history of technology. Three visuals: Sawmill Machine (Besson, 1578); Nomogram (d’Ocagne, 1862); and Ratchet Device (da Vinci, 1500) of the past practice were selected for the comparison with the current visuals. The current visual tools, which were identified as having positive impact to students’ learning were: Sustainable Design Poster (Storer, 2005); Ecodesign Web (Lofthouse and Bhamra, 2005); and Kite Posters (Beh and Norman, 2009). These past and current visuals were selected
based on their recognised and reported quality as they supported designing and innovation.

These 6 visuals were analysed initially using the author’s hypothesis – the KEPs, and found to fit within the first 3 categories of the KEPs. According to their similarity of KEPs, they were sorted in pairs as follows:

1. Visuals from Besson (1578) and Storer (2005) were found to fit into KEP-1: COMPARE > RELATIONSHIP. Both visuals held the intention of allowing the viewers to compare relationships and the interaction between humans and technologies, which were used to communicate extensive messages about products, processes, proportions, materials, etc.

Relating these visuals to other experts’ perspectives:

- Its analytical structure is similar to a ‘timeline’ (Kress and van Leeuwen, 1999), where a process is depicted originating from the most inner section in ‘space’ (Engelhardt, 2006) and moved forward to the front of the plane. The captions corresponding to each abstract ‘object’ make the meaning clear. This matched the principles of graphics language, ‘make the abstract concrete’ and ‘clarify complexity’, by Malamed (2009). The overall representation is quite ‘objective’ in attitude and ‘knowledge-oriented’ (Kress and van Leeuwen, 1999).

- Its analytical structure is ‘drawn accurately without scale’ and the ‘objectivity’ is about being ‘knowledge-oriented’ (Kress and van Leeuwen, 1999). The drawn image illustrates the look of the machine, and provides information about its operation, function and the approximate size of the machine. These messages could only be obtained by comparing the main ‘object’ (machine) and ‘sub-object’ (human) that had played the important role; the ‘space’ and
‘properties’ managements are well handled to bring out detailed elements of the machine (Engelhardt, 2006).

• The human figure, in fact, included as the ‘sub-object’ not only possesses clear meaning, but also enriched the content of the drawing. If this drawing was without the figure, then it only encodes what the machine looks like, not other information. This matched ‘make the abstract concrete’ and ‘clarify complexity’, however the detailed properties are against the principles of ‘reduce realism’ of Malamed (2009).

2. Visuals from d’Ocagne (1862) and Lofthouse and Bhamra (2005) were found to fit into KEP-2: FORM > FUNCTION. These 2 visuals were about their ultimate use as aids or tools to guide further design decisions.

Relating these visuals to other experts’ perspectives:

• Its analytical structure is about ‘scale’ and the ‘objective attitude’ is ‘action-oriented’ (Kress and van Leeuwen, 1999), where this matrix served as a tool for plotting specifications that were meant for the purpose of analysis.

• The visual tool itself looks abstract, however its specifications, division lines, colours scheme, legend, served as clear ‘object’, ‘sub-objects’ and ‘properties’ (Engelhardt, 2006), to make the meaning clear and of easy to use. This matched the principles of ‘make the abstract concrete’ and ‘clarify complexity’ (Malamed, 2009).

• Its analytical structure is about ‘scale’, with additional aspects of ‘size, number and quantity’; and the ‘objective attitude’ is ‘action-oriented’ (Kress and van Leeuwen, 1999). This matrix served as a tool to calculate
mathematical solutions.

- The ‘properties’ (numbers, matrix grids and dimensions) application in an action-oriented ‘space’ (Engelhardt, 2006) make the matrix abstract, but easily visible and usable at first glance. This also matched the principles of Malamed (2009), ‘direct the eye’ by grid-lines, ‘make the abstract concrete’ and ‘clarify complexity’ as it simplified the method of complex calculation, where by a glance the BHP (size of engine) can be obtained.

3. Visuals from da Vinci (1500) and Beh and Norman (2009) were found to fit into KEP-3: PRECISE > TRUTH. Both visuals were traced to the means of communicating designed or studied details, which were about informing the extensive technological aspects or features for further understanding and inspiration purposes.

Relating these visuals to other experts’ perspectives:

- Its analytical structure is about ‘parts and whole’ and ‘drawn accurately without scale’; and the ‘objective attitude’ is ‘knowledge-oriented’ (Kress and van Leeuwen, 1999). The concept of ‘whole’ was highlighted with the accompanying ‘parts’ or details to provide useful accurate formation of structure.

- The ‘object’, ‘sub-objects’ and ‘properties’ (Engelhardt, 2006) play an important role in providing the approximate accurate information about connections, assembly, functions, solutions, etc.

- The overall structure and layout of graphics also matches
the principles of ‘direct the eyes’ and ‘clarify complexity’ of Malamed (2009).

These 3 pairs of visuals were further investigated through the eye-tracking method, in association with conventional techniques (interview prompts and verbal protocol), in order to gather both qualitative and scientific empirical evidence. This combination of methods allowed the KEPS to be described in terms of the intentions of the originators of the visuals and to be validated against the interactions as experienced by the readers. Therefore, this was seen to be an appropriate strategy to validate the embedded design intentions in order to check the validity of the triangulation evidence concerning the KEPS of VCT.

The validation analysis using eye-tracking derived the following outcomes:

- The selected 16th Century visuals and those visuals in current practice shared similar qualities of KEPS. The applied KEPS-1, -2 and -3 were traced through eye-scanning paths, as well as via the descriptions by the participants.

  - **Pair-1**: The human figure in both visuals, as the central focus, was used by all 5 participants as a benchmark in reference to other objects surrounding it for the purpose of ‘comparing’ and making ‘connections’, so as to be able to find possible ‘relationships’ within, and hence to encode the story or messages embedded in the visual representations (evidence in sections 6.4.1.1 until 6.4.1.3 and Table 6.11). These key eye movements and mental activities were as anticipated and intended by the KEP-1 (COMPARE to reveal CONNECTION and RELATIONSHIP).

  - **Pair-2**: Both visuals were identified by all 5 participants as a type of matrix. They also identified that both visuals matrices could provide almost precise information and/or accurate scales, only one is by descriptions and with a colour scheme; and the other is by using numbering scheme. The representations were treated as visual forms
that functioned through potting data to establish a design criterion; and hence they matched the intention of the KEP-2 (Unity of FORM to accentuate FUNCTION), evidence in sections 6.4.2.1 and 6.4.2.2, Tables 6.12, 6.14 and 6.15.

- **Pair-3**: Both visuals were identified by all 5 participants as being about the design or making of a product. They shared the same view that both visuals provided almost precise information and almost accurate details, which could assist the making or building of that product. The only difference was that one had some measurements; and the other was without any given dimensions. Both representations matched the KEP-3 (PRECISION of data to communicate ACCURACY or TRUTH), evidence in sections 6.4.3.1 and 6.4.3.2, Tables 6.16, 6.17 and 6.18.

Thus, these results confirmed the evidence that KEPS were effective in assisting readers in navigating the visual in order to follow the information encoded and/or embedded and reach the understanding hoped for, as in the earlier 2 studies in the triangulation. This was very much like ‘directing the eye’ as in Malamed’s (2009) graphics and visual language principles. This also meant that KEPS work through providing visual emphasis. Whereby, the 6 studied visuals possessed the structures or elements of ‘whole’ and ‘parts’ (Kress and van Leeuwen, 1999); and also were effectively laid out and utilised the idea of objects, space and properties for structuring useful visual language that were comprehensible (Engelhardt, 2006).

Consequently, the overall results from these 3 studies in CS2 revealed that the KEPS were appearing to assist visual reading and understanding of VTIs; and which could be traced via ‘scientific’ or ‘non-scientific’ methods. Both qualitative and scientific evidence was obtained from these 3 studies in CS2. As to furthering the understanding of ‘how do these KEPS work in VCT?’ and ‘how does this VCT work in the link of VC, designing and creativity?’; it could be concluded that the KEPS played essential roles in enhancing the visual aspects for VCT, and hence VCT could be used...
to support modelling and designing processes in order to facilitate creativity and/or innovation.

The empirical data from this CS2 provided evidence supporting the emerged KEPS from the literature review, and hence confirmed the hypothesis. These data could be valuable in contributing knowledge of strategies for preparing teaching and learning materials in the form of visual communication in delivering technological knowledge, skills and values.

8.3 VCT and KEPS In A Richer Context – Materials Technology

The empirical data from CS1 revealed that VCT could be used to support modelling and designing processes in order to facilitate creativity and/or innovation. Whilst, the 3 studies in CS2 obtained empirical data that the KEPS were appearing to assist visual reading and understanding of VTIs; and therefore it could be concluded that KEPS played essential roles in enhancing the visual aspects for VCT.

As a consequence, it was thought necessary to carry out more in-depth investigations in order to confirm the validity of VCT and its KEPS within a specific technological aspect of visual representations. Thus, Case Study-3 (CS3) was designed, putting VCT and its KEPS in a richer context within Materials Technology for further investigations.
8.3.1 Case study context from literature review

The literature review revealed that there are distinct differences between ID and ED, as shown below:

<table>
<thead>
<tr>
<th>ID</th>
<th>Versus</th>
<th>ED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Perceptions:</strong></td>
<td>Vs.</td>
<td>Vs.</td>
</tr>
<tr>
<td>• Industrial designers are visual thinkers concerned with aesthetics (Cagan and Vogel, 2002).</td>
<td>• Engineering designers think in terms of function and cost (Cagan and Vogel, 2002).</td>
<td>• They are conceptually based and have one-direction thinking for problem-solving (Wu, 2012).</td>
</tr>
<tr>
<td>• Thinking in their minds is very complex, and they always search for multidimensional solutions for problems, which makes them more connected to the complexity of the real world (Wu, 2012).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. <strong>Skills &amp; Design Requirements:</strong></td>
<td>Vs.</td>
<td>Vs.</td>
</tr>
<tr>
<td>• Concern with the user-related aspects of product appearance; where form, usability and personality of product are to be focused by employing the use of visual design representations to externalise and communicate its ideas (Kim et al., 2006; Oakley, 1990; Pei, 2009; Wikström, 2001).</td>
<td>• Relate to the structure, function and manufacture of the product, which involve problem definition, conceptualisation, embodiment and detail design (Shigley and Mischke, 1989; Pahl and Beitz, 1996; Pei, 2009; Ullman, 2003).</td>
<td>• Design requirement supports product’s physical principles, mechanical system, and proper technical functioning such as its mechanical and thermal performance, cost and durability (Ashby, 2005; Ashby and Johnson,</td>
</tr>
</tbody>
</table>
2004, p. 27).

- ID designing is described as dissecting, recombining, permuting and morphing ideas and images (Ashby and Johnson, 2004).

- Design is seen as aesthetic and perceived values that the product character is described by the demand of clients (Ashby and Johnson, 2004).

Vs.

- ED designing as linear and sequential thinking model, using verbal reasoning and mathematical procedures to establish an absolute and precise specification – it moves from the ‘known’ to ‘unknown’ by analysis (Ashby and Johnson, 2004; Pugh, 1990).

- Design is about how a product works and how it is made (Ashby and Johnson, 2004).

3. Visual Representations:

- Its visual representation would be more of an artefact form (Dym and Little, 2003).

Vs.

- Its visual representation would only display a detailed description of a design proposal for manufacture, not an artefact form (Dym and Little, 2003), and tend to be more calculations-based, presenting technical data and are usually very precise (Pei, 2009).

4. Materials Technology:


Vs.

- Technological contents related to materials technology: materials, processes, workshop practice, manufacturing, engineering science, and mechanical engineering, where the last 2 contents are related to materials science (Myerson, 1991).
• ID is heavily concerned with the aesthetics of materials, and the aesthetics of interaction between people and materials, and so its core concern is how materials influence people's experiences of products, either in use or as objects to behold (Pedgley, 2012).

Vs.

• ED is occupied heavily with the performance of components that interact with other components, rather than interfacing with users (Pedgley, 2012).

5. Similarity between ID and ED:
• Both use representations to better understand the problem and to communicate with others (Burghardt, 1999; Pei, 2009).

• Both use drawings (only in different format) for ideas generations (sometimes distinct, sometimes tentative) which involve observations and manipulations within their mind’s eye (Ferguson, 1993).

Besides those characteristics, the investigations in CS3 also looked at the differences in countries and levels of education between the 2 groups of the ID and ED students, as follows:

6. Countries/Cultures:
• Western country: England Vs. Eastern country: Malaysia

• Middle Eastern: Turkey
  (which is often seen as on the boundary between the East and West)

7. Educational levels:
• Undergraduates Vs. Masters
The literature review also revealed that Materials Technology plays an essential role in ID and ED (section 2.3.2 and 2.3.3, Chapter 2). The material itself and the technology of producing it provide space for integration between technical/engineering design to meet functionality requirements, and industrial design for proper consideration of the aesthetic needs in the design of a product (Ashby and Johnson, 2003).

As a result of the current trend for markets’ to value the expressive feel of a product’s appearance, many researchers seem to be changing from placing the main emphasis on engineering aspects to a more balanced approach between technical and sensorial properties (implied in Special Files papers in METU, 2010; Ashby and Johnson, 2003).

Following these shifts in emphasis, the visual tools used in representing and approaching the context also seem to have moved from typically ‘technical and linear’ diagrams to more complex representations. Materials technology serves as a rich context for the education of designers, and therefore, was appropriate as a setting for further investigations into the validity of the VCT and KEPS. This study of VCT and KEPS as in CS3 completed the macro-triangulation cycle of the whole research agenda.

8.3.2 Case Study-3: VCT and KEPS within the context of materials technology

The first phase of Case Study-3 was designed to undertake the analysis of the overall visual presentation and the visual representations used in 2 books on materials technology for ID and ED students. This then led to the next step of analysing selected diagrams (or VTIs) from the 2 books, along with other complex visual representations used in Special Files papers (METU, 2010) which related to the new conception of materials technology for designer. Redesign of the existing visuals was carried out utilising the KEPS after the analysis, and this was where the author’s own practice of design was applied.
Feedback from the questionnaire survey concerning the redesigned versions of the visual representations, ultimately, tracking the key aspects of the KEPs was obtained. These approaches in CS3 allowed the question of whether the KEPs still worked in richer contexts for the communication of technological information to be answered.

**PHASE-1 of CS3: Analysis of books on materials technology for ID and ED students**

The visual representations from the 2 books were analysed and evaluated through four observation lenses, as follows:

1. **Types of Models** (based on Baynes, 2009 – the nature of model)
2. **Graphical Strategies** (based on Danos, 2009 – graphicacy categories)
4. **KEPs of VCT** (Beh and Norman, 2009)

The first 3 were ‘found’ lenses, allowing different perspectives of VC and graphical strategies, principles and techniques to be analysed in order to track the applications of VCT. The 4th lens came from the analysis of a literature review (Beh and Norman, 2009), which was undertaken to explore the validity of good practice of VCT in CS2. The lenses were used to articulate the principles that had been applied in VCT practice.

**PHASE-2 of CS3: Analysis, redesign and survey of VTIs applied KEPs**

The analysis of the 7 selected representations was focused on their use of forms, layouts and detailed visual elements and/or annotation applied in them. These foci were the key aspects to determine the effectiveness of communication, particularly, in delivering their messages through the depicted images and/or even a line (a form of graphic). The established KEPs were used as guidelines to assess and analyse the strengths and weaknesses of the selected representations.
Subsequently, redesigned versions were developed to strengthen the weaker aspects that had been identified (detailed analyses and illustrated redesigns can be found in section 4.3, Chapter 4). Out of the 7 VTIs, 5 were selected for further investigation through a questionnaire survey (the full questionnaire can be found in Appendix 7.1). The structure of the questionnaires was based on the following foci:

- Understanding of the messages carried in the diagram
- Value of the diagram for the design practice
- Judgement of effective visual representation
- Features that catch the attention
- Features that enabled understanding of the message
- Additional comments (if have any)

The survey was intended to gather data concerning reading preferences, perceptions and interpretation of visual information within the context of materials technology.

8.3.3 The findings of VCT and KEPs within the context of materials technology

Within the triangulation of CS3, literature review was first explored and found the new agenda and new emphasis of requirements for materials technology. It was also found that the visual representations had changed, from technical and linear to more complex depictions since the shifting of emphasis and agenda, as mentioned earlier in section 8.3. The second method was analysing the presentation and representations of VCT used in the materials technology books for the ID and ED students. In completing the triangulation, analysis of VTIs, redesigns applied the KEPs, and questionnaire surveys of the redesigned VTIs were conducted. These two studies: the books analysis and the diagrams/VTIs study have established the following findings.
Analysis of books on materials technology for ID and ED:

- Different types of representational models were used in those 2 books: the ED book used more SYMBOLIC types as compared to the ID book that used more ICONIC types (Table 7.4 and 7.5, Chapter 7).

  The finding for the ED book seems similar to the views from the literature that ED visual representations would tend to be more calculations-based, presenting technical data and are usually very precise (Pei, 2009). Whereas, the SYMBOLIC models according to Baynes (2009, p. 10), “are the models that work by using an abstract code to symbolise aspects of existing or proposed reality”.

  The ID visual representations were expected to have more of an artefact form (Dym and Little, 2003); and be concerned with the user-related aspects of product appearance, where form, usability and personality of product are to be focused by employing the use of visual design representations to externalise and communicate its ideas (Kim et al., 2006; Oakley, 1990; Pei, 2009; Wikström, 2001). This matched the results that were more ICONIC types of models used in ID book.

  Baynes’s (2009, p. 10) ICONIC models refer to those “looking like (or sounding or tasting or feeling like) a selected aspect of existing or proposed reality. Waxworks and toys come into this category but so does much visual art and many of the models used by designers to develop and explain their proposals.”

- Different graphical strategies were used: the ED book’s graphical strategies were largely confined to using the SEQUENTIAL category; whereas, the ID book used various and mixtures of graphical strategies to attain communication impact (Table 7.6 and 7.7).
The results of the ED book were similar to those expected from the literature findings e.g. ED designing as a linear and sequential thinking model, using verbal reasoning and mathematical procedures to establish an absolute and precise specification – it moves from the ‘known’ to ‘unknown’ by analysis (Ashby and Johnson, 2004; Pugh, 1990). This was similar also to Wu’s (2012) description of the ED students as conceptually-based and trained, and that they have one-directional thinking for problem-solving. Danos’s (2009, p. 82) taxonomy of graphicacy described the SEQUENTIAL category as: “images illustrate the sequence of a thought, process or story by following a relative sense of direction”, and this was took the same logic from the ‘Lineal’ category of graphs by Fry (1974), as cited by Danos (2009).

The finding that the ID book used various mixtures of graphical strategies was also parallel to the literature review, which revealed that ID designing is described as dissecting, recombining, permuting and morphing ideas and images (Ashby and Johnson, 2004). Also, thinking in the ID students’ minds is very complex, and they always search for multidimensional solutions for problems, which makes them more connected to the complexity of the real world (Wu, 2012).

Those views from the literature seemingly imply that various things or strategies were happening within the process of thinking and handling design processes in ID, which parallels the various mixtures of graphical strategies applied in the ID book representations. This appeared to be the reasoning behind Ashby and Johnson’s (2004) explanation and adoption of this strategy in their ID book.

• There was some evidence of similar graphical techniques being applied in the ED and ID books, but there were more examples in the ED book (as having more statistical VTIs); and less in the ID book, where very little statistical information was provided.
The analysis using this third lens was difficult to employ to cover the whole ID book’s representations, because the basis of Tufte’s (1990; 1997; 2004; 2006) principles and techniques were specifically meant for quantitative statistical graphical information design.

The ID book contains very few of this type of VTIs. However, 2 examples (1 from ED book; 1 from ID book) were analysed using this lens-3 from the 2 books. Findings of the strengths and weaknesses in each visual (1 statistical type; 1 non-statistical) were obtained (detailed elaborations can be found in section 7.3.1: Lens-3 on the 2 chapters of the ED and ID books).

- There was some evidence of similar KEPs of VCT being applied, but not completely successfully according to the KEPs criteria. Four VTIs (2 from the ED book; 2 from the ID book) were put in 2 pairs, according to the similarity of the nature of the diagram, to be analysed in regards to their strengths and weaknesses correspondingly to the criteria of the 4th lens (the KEPs). One pair was shown not to have applied the KEPs criteria; whereas, another pair was shown to have close correlation with the KEPs criteria (detailed elaborations as in section 7.3.1: Lens-4; and Table 7.8). These findings had brought forward these 4 VTIs to the next stages of redesign and investigation through the questionnaire survey.

Furthermore, the last 2 lenses (lens-3 and lens-4), in fact, were not similar to the types of models or types of strategies lenses, where a distinct type of difference can be identified one way or the other. Rather, these 2 lenses were only suitable for use to examine the individual diagram’s visual impact such as its form, layout and other detailed graphic elements applied to encode objective meanings. That was why the author had stated that ‘there was some evidence of similar graphical techniques being applied in the ED and ID books’, but was unable to state which one was having more strength than the other.
Analysis, redesign and survey on materials technology VTIs:

Conversely, the findings within the analyses, redesigns and questionnaire survey of VTIs used in materials technology contrasted with the analysis results obtained from the 2 existing materials books, and also with the expectations of differences between ID and ED from the literature review. The findings included:

- Most of the redesigned VTIs (applied the criteria of KEPs) were more noticeable, understandable and more effective in communication as compared to the original VTIs (the statistics are shown in Tables 7.17, Chapter 7). However, 2 of the VTIs (Figures 7.17 and 7.18 as of questions 2 and 3 in questionnaire) showed slightly less evidence of understanding; but still obtained higher percentages of more noticeable and more effective visuals.

This statistical result was unable to conclude that these 2 VTIs provided less understanding as an overall judgement (in the author’s view). This is because the numbers of respondents who had chosen these 2 original VTIs as effective, noticeable and understandable visuals only represented a very little percentage. This meant that the small number of people (e.g. only 4 out of 47 total numbers of respondents and which only stood for 9%) represented 100% understanding. However, the large number of respondents (43 of 47 which represented 91%) represented 82% of understanding. Thus, this statistic of 82% does not represent the VTI evaluated less understandable, due to the numbers involved the statistic could not be compared.

There was no difference in communication impact using VCT for the ID and ED students, as well as for the 3 different countries which are in 3 different regions of the world (Tables 7.10-7.16; similar evidence was also obtained in CS2 which involved participants from the UK, Cyprus, Singapore, and Mexico). This means that there was no evidence of cultural differences affecting the VCT, particularly concerning understanding.
However, there was some evidence of differences in VCT comprehension at different levels of study (educational background). This result was gathered from the questionnaire survey regarding the redesigned VTIs (Tables 7.16; survey questions: 2, 5 and 6; Figures: 7.17, 7.20 and 7.21).

The redesigned VTIs were embedded with slightly more visual hints with the intention of providing elements for comparison, making connections and relationships (so as to achieve the criteria of KEP-1). This approach resulted in the redesigned VTIs being the most noticeable, understandable and effective visuals amongst all the undergrads respondents. However, the respondents from the masters’ level thought that the redesigned version had lost some of the aesthetic qualities or ‘essence’ for designers. Therefore, a possible implication could be that as a result of the processes involved in reaching a higher education level, a more ABSTRACT form (less visual hints) had become potentially understandable and preferred.

In fact, the mentioned aspects of the aesthetic qualities/essence for designers were also noticed by the author toward the end of the redesigning processes, but they could not be furthered modified due to time not being available. These issues were further investigated during the discussion with the materials experts for the following stage of study.

8.3.4 Validity of the triangulation in CS3

These findings (the analysis of books and redesigned VTIs survey) were further validated through discussion sessions with material experts from 3 higher institutions in 3 different countries of the 3 different regions. Although there were different methods used to gather discussion outcomes from these 3 materials experts, the views from the 3 experts were considered valid in representing their own stand-points and positions. The methods applied were: only 1 expert was available for a conventional discussion session in LDS, LU. For the other 2 experts (1 in Turkey and 1 in Malaysia) correspondence using email was used. The discussion in this section will report experts’ view in relation to the following 3 issues:
• Whether ID and ED students need different styles of VTIs to understand information concerning materials.
• Whether the results obtained from the books analysis, VTIs analysis and redesigns, and the questionnaire survey of the VTIs were as expected.
• Their views regarding cultural differences in relation to understanding of VTIs or VCT.

A mixture of views was gathered from the session of experts’ discussions. Some of the views supported the literature review findings, and some views supported the empirical evidence from this CS3, as follows:

• Two of the experts’ views supported the literature review that the ID and ED students should have understood better VTIs that were presented in different styles of representational models, and use different types of graphical strategies and techniques (section 7.3.4, Table 7.18). This is due to the distinct nature of roles that they play in the real world practice (Chok, 2012). A similar view of Pedgley (2012) was that “ID and ED do need different styles of VTI for materials, with regard to the representational models used. This is because in my view ID and ED are significantly different disciplines in the way that they use materials and for what purposes.”

He also added “ID is heavily concerned with the aesthetics of materials, and the aesthetics of interaction between people and materials, and so its core concern is how materials influence people’s experiences of products, either in use or as objects to behold. On the other hand, ED is occupied heavily with the performance of components that interact with other components, rather than interfacing with the users. From this viewpoint, it would follow that material representational models should be obviously user-centred for ID, but this emphasis is not necessary for ED” (Pedgley, 2012).
However, 1 expert thought the opposite; his views being that the differences between ID and ED students were only due to their exposure to different educational and training backgrounds. Once the VC was introduced, then this might change the perspective of VTIs amongst the ED students. Because he believed that the nature of people’s minds does work or see visuals in the first instance, as this fact, can be observed from ‘little kids’ (Wu, 2012). He also provided an example of his Materials Engineering students, before being exposed to visual representations; they were content with their status quo. However, after being exposed to visuals, the students showed signs of acceptance and preference. His perspectives (section 7.3.4, Table 7.18), in fact, supported the research evidence of this CS3 (sections 7.3.1 to 7.3.3).

• Two experts were surprised to see that a slight change in the redesigns could impact on the effectiveness of visuals and understandable qualities of the VTIs; and that also the ED students were more drawn to understand VTIs which were depicted by graphics clues (the redesigns) from the survey (survey comparison evidence in Table 7.16). Whereas, 1 expert thought that the research findings matched his expectations, because those graphics provided good visual associations, which connected to the real world situations, and that this aspect should help younger people to understand the messages intended.

Since 2 of the materials experts were quite surprised in seeing how ‘a slight change impacted the outcomes of the redesigned VTIs’, it was thought that by providing a visual example demonstrating this aspect would be useful addition to this discussion. Visual-M (the redesigned VTI, Figure 7.23) was quite highly valued as visually effective and easier to understand as compared to the original visual by more than 3 quarters of the overall respondents (Q7, Table 7.17). So, by using this VTI as an example for further analysis, its visual emphasis could have been further enriched through the observation lens-3, based on Tufte’s (1990; 2006) techniques for statistical information design.
In particular, in the author’s view, ‘links and casual arrows’ and ‘layering and separation of data’ (Tufte, 1990; 2006) aspects could be refined in order to yield greater visual impact.

To demonstrate how these 2 aspects work, see the comparison between Visual-M and Visual-O (Figure 8.2); by only making ‘a slight change’ from a dashed-line cycling arrow to a solid-line circle (changed in ‘links and casual arrows’), the whole visual message had changed in terms of ‘layering and separation of data’. The newly refined visual message showed that the main cycle of activities were separated from the secondary cycles of activities. The graphic elements of lines had visually made the primary information stand out and the secondary information become slightly set back to a secondary level. Therefore, the visual clues had become clearer to viewers at a glance, and then lead the viewers towards the detailed and intended messages. This demonstrated that ‘a slight change’ of graphic elements could significantly influence the overall visual impact.
Figure 8.2
Validated Material Selection Activities and Information Sources Used: Visual-O is an improved version of Visual-M (Beh and Yap, 2011; adapted from van Kesteren 2010, p. 326)
• All 3 experts shared the same views of VTIs in relation to the cultural aspects; where 3 of them agreed that visual communication for technical purposes should be approached in the same way for all cultures as students all around the world should have learnt quite similar technical content if they were in the same discipline. However, 2 of the experts did not consider ID and ED as different cultural contexts within a community. However, 1 of them did also consider ED and ID as a difference in cultures, but through his experiences with both ED and ID students, he believed that VTIs should have no cultural barrier. These experts’ point of views supported the evidence of CS3.

The findings from these 3 studies in CS3 turned out to be a mixture of views, where the evidence obtained from the 3 studies did not point to the same direction.

The data obtained about the VCT from the analysis of the 2 books on materials technology for the ID and ED was similar to the views gathered from the literature review, and the views from 2 of the experts of materials in the validation discussion. This obviously revealed that the 2 existing books were designed based on the same perceptions about the ID and ED, about their distinct differences of nature, skills and design requirements, visual representations needed and materials technology requirements, as traced from literature review (discussed in section 8.3.1).

The redesigning exercise of the author’s own practice, which applied the KEPS to redesign the existing VTIs for the purpose of more effective VCT, again showed significant evidence of visual effectiveness and easy of understanding capability (besides the evidence from CS1 and CS2). This evidence was obtained from the questionnaire survey amongst 3 higher institutions from 3 countries and within the ID and ED students. Thus, the empirical evidence revealed the workability of the KEPS, and hence the criteria of KEPS were appropriate for developing VTIs for the use of effective VCT.
Within the same survey, evidence also revealed that ID and ED students of different cultural backgrounds did not require different VTIs or the use of different strategies of the VCT for effective communication. These findings gained strong support from 1 of the experts, but only a little support from the other 2 materials experts during the validation discussions. However, these findings do not match what had been revealed from literature review.

This seemed similar to the evidence obtained in CS1 regarding the ED students’ perceptions towards VCT/VTIs i.e. that those VTIs were not useful, but evidence traced that the preferred problem-solving sources for the ED students were drawn from the VTIs (discussed toward the end of section 8.1.4).

**PART II**

Discussion in this section is based on the case studies, or Part-1 outcomes, in relation to the research objectives.

**8.4 Research Findings Corresponding to the Research Objectives**

The empirical data from this CS2 supported the emerged KEPs from the literature review, and hence confirmed the hypothesis that the KEPs represent. CS2 revealed that the KEPs were appearing to assist visual reading and understanding of VTIs. The redesigning exercise of the author’s own practice in CS3, which articulated the KEPs in the redesign of the existing VTIs for the purpose of more effective VCT, again showed significant evidence of visual effectiveness and easy understanding capability within a rich context of materials technology. These findings achieved the objective-1 below.

**Objective 1:** To investigate the principles behind the communication of technology, predominantly focusing on the general visual communication of technological information.
CS1 revealed that VTI was effective in communicating knowledge, skills and value, and that the designerly activities were about the competencies of knowledge, skills and values. CS1 obtained evidence of links between VCT, designerly activities which involved knowledge, skills and values within the technological communication, and facilitates creativity. In addition, CS2 revealed that the KEPs played essential roles in enhancing the visual aspects for VCT, and hence VCT could be used to support modelling and designing processes in order to facilitate creativity and/or innovation. This empirical evidence accomplished the objective-2, as shown below:

**Objective 2:** To explore the learning of technology through visual communication and achieving creativity and innovation in designing.

CS1 revealed that the ID and ED students’ perceptions of VCT/VTI, and the kite-design outcomes showed that there were distinct differences between the ID and ED students. However, their preferences of using the VTI for solutions were traced to be similar. The 2 books on materials technology for the ID and ED were matched to the descriptions and expectations from the literature review, and the views from 2 of the materials experts in the validation discussions, which suggested that the ID and ED students were expected to be using difference types of representational models and graphical strategies of VCT in their learning. However, the evidence from CS3 also revealed that ID and ED students, also from different cultural backgrounds do not require different VTIs or the use of VCT for effective communication. This empirical evidence revealed the workability of the KEPs, and hence the criteria of the KEPs were appropriate for developing VTIs for the use of effective VCT. These completed the objective-3 as follows:

**Objective 3:** To explore and evaluate existing visual communication tools or resources for industrial and engineering design teaching and learning environments.
Chapter 9  Conclusions

Chapter Overview

Chapter Nine concludes the findings of the research and reflects on the contribution of knowledge. Recommendation for possible further research and development are discussed.

Figure 9.1 illustrates how Chapter Nine fits into the structure of this thesis.
9.1 Conclusions

9.1.1 Case Study-1: VCT > Designing > Creativity

There were 3 positions from the VCT in CS1 that can be concluded as follows:

1. CS1 revealed that VTI was effective in communicating knowledge, skills and values, in particular, within the aspects of the following:
   - ‘Knowledge’: Control and Energy (empirical evidence obtained of these 2 aspects).
   - All aspects in ‘Skills’: Investigation, Invention, Implementation and Evaluation has been supported through empirical data.
   - ‘Values’ in term of the Technical and Aesthetic categories were supported through empirical data.

   [NB: This achievement answered RQ2: How is visual communication used to communicate knowledge of technology? and RQ1: What is visual communication? was mainly answered through literature review.]

2. CS1 obtained evidence of links between VCT, designerly activities which involved knowledge, skills and values within the technological communication, and of facilitating creativity.

   [NB: This achievement answered RQ3: What are the links between visual communication of technology, designing, creativity and innovation?]

3. The ID and ED students’ perceptions of VCT/VTI, and the kite-design outcomes showed that there were distinct differences between the ID and ED characteristics. However, their preferences of using the VTI for solutions were traced to be similar.

   [NB: This achievement answered RQ8: How is visual communication used to communicate technological information to ID and ED student designers (within the 18 to 25 age range) in higher education around the world?]
9.1.2 **Case Study-2: KEPs of VCT**

There were 3 positions from the KEPs of VCT in CS2 that can be concluded as follows:

1. KEPs were appearing to assist visual reading and understanding of VTIs; and which could be traced via objective or subjective data gathering. This refers to either through the participants’ reading patterns (eye-scanning paths which were traced by the eye-tracker device) or with the descriptions of their understanding. The understanding aspect could be evaluated from descriptions of perceptions toward visual elements, and the participants answers to questions.

   [NB: This achievement answered RQ2: How is visual communication used to communicate knowledge of technology?]

2. KEPs played essential roles in enhancing the visual aspects for the VCT, and hence VCT could be used to support modelling and designing processes in order to facilitate creativity and/or innovation (in relation to CS1). Hence the KEPs can provide useful guidelines for structuring the development of and evaluation criteria for visual representations or tools.

   [NB: This achievement answered RQ3: What are the links between visual communication of technology, designing, creativity and innovation? and RQ7: What are the effective methods for visual communication of technological information?]

3. The empirical data from this CS2 supported the emerged KEPs from the literature review, and hence confirmed the hypothesis that the KEPs represent.

   [NB: This achievement answered RQ7: What are the effective methods for visual communication of technological information?]
9.1.3 Case Study-3: VCT and KEPs in a Richer Context (Materials Technology)

There were 4 conclusions about the VCT and its KEPs from CS3 as follows:

1. The VTIs in the 2 books on materials technology for ID and ED matched the descriptions and expectations from the literature review, and the views from 2 of the materials experts in the validation discussion, which suggested that the ID and ED students were expected to be using difference types of representational models and graphical strategies of VCT in their learning.

   [NB: This achievement answered RQ2: How is visual communication used to communicate knowledge of technology?]

2. The redesigning exercise of the author’s own practice in CS3, which articulated the KEPs through the redesign of the existing VTIs for the purpose of more effective VCT, again showed significant evidence of visual effectiveness and easy understanding capability (besides the evidence from CS1 and CS2).

   [NB: This achievement answered RQ7: What are the effective methods for visual communication of technological information? and RQ8: How is visual communication used to communicate technological information to ID and ED student designers (within the 18 to 25 age range) in higher education around the world?]

3. This empirical evidence revealed the workability of the KEPs, and hence the criteria of KEPs were appropriate for developing VTIs for the use of effective VCT in the materials technology context.

   [NB: This achievement answered RQ7: What are the effective methods for visual communication of technological information?]
4. Within the same survey, evidence also revealed that ID and ED students, even with different cultural backgrounds did not require different VTIs or the use of VCT strategies for effective communication. These findings gained strong support from 1 of the experts, but only weaker support from the other 2 experts of materials through the validation discussion. However, these findings did not match what have been revealed from literature review.

[NB: This achievement answered RQ8: How is visual communication used to communicate technological information to ID and ED student designers (within the 18 to 25 age range) at higher education around the world?]

9.2 Contribution of Knowledge

Based on the literature review, some guiding sources were found and the KEPs for good VCT practices were established. The KEPs were tested via the objective method of eye-tracking in order to check their application on some visuals from the non-specific context. These non-specific context visuals included kite-VTI in a poster format; a poster to inform about sustainable and technological concerns within product design; a drawing of the assembly and operation of machine for mechanical engineering design; and visual tools/diagrams for design-decision-making. The KEPs testing was then extended through using a non-objective method, the author’s own design practice together with questionnaire surveys. The KEPs were further validated through exploring visual representations in the emerging context of sensorial properties and materials technology (a richer context) with students of different cultural backgrounds from 3 selected higher education institutions. These strategies have demonstrated the effectiveness of the KEPs and VCT, which were shown to potentially provide a universal language amongst ID and ED students with different aspects to their backgrounds (i.e. visual elements that were commonly understood by these design students).
Although the KEPs seem to have emerged and attained quite convincing results throughout the research activities, the author believed that they still require further development. More detailed criteria or guidelines are needed in order for them to be used by others and to facilitate the development of visual resources for teaching-and-learning purposes. To achieve this, evaluation by educators on teaching and learning resources using the KEPs, and evaluation by graphic designers on the detailed aspects of visual elements are potentially useful and reliable approaches to be conducted for the next step. Following that, a documented handbook on the design of technological visual resources, including the KEPs of VCT, the detailed findings from the evaluations process, and some other detailed design tips (e.g. some great examples could be adopted from Tufte’s and Pettersson’s principles), would be useful to guide the designers/developers to construct potentially good technological visual resources.

Empirical evidence of the associations of VCT within modelling, designing, creativity and innovation were successfully traced in the task of kite-designing. Whereby, the VCT was found to be a useful tool or strategy to facilitate the delivery of technological knowledge, skills and values within ID and ED design education. The concepts of ‘Knowledge’, ‘Skills’ and ‘Values’ were significant in this research context because these 3 aspects of technology for the purposes of those engaged in designing are important in setting the boundaries and limitations for designers within designing processes. Additionally, they were taken as the guiding principles for analysing competencies for the design education content and activities.
9.3 Limitations

Within the thesis, there was only one case study of designing, CS1 – ‘the kite-designing-task’, provided the empirical evidence of the association between VCT, designing and creativity. Researching different design contents would probably lead to further insights relating to different technologies.

There are also outstanding concerns in relation to cultural issues. The research was conducted through examining the cultural differences in terms of ID and ED as the educational background within a community; and the differences within students from 3 totally different countries from 3 regions of the world (the UK, Turkey and Malaysia). The number of countries represented could be extended to more thoroughly represent regions by using larger samples and in order to achieve reliability.

Although the KEPS were validated through CS2, using both an objective method (eye-tracking) and non-objective method (own-design-practice), they were developed based on a literature review, which generated broad-based KEPS. Therefore, these KEPS cannot be treated as the final emerged principles as they need further refinement or detailed guidelines (as explained in section 9.2).

It was only one technology (Materials) that was explored as a richer context that has undergone the articulation and investigation utilising the KEPS and VCT in CS3; moreover, CS3 also involved only 3 higher institutions within 3 countries. Whereas, in the reality of design education, there are many other technologies involved in designing, and hence it is necessary to investigate more technological contexts. The validity could be even more credible if the research involved design education at various levels and all around the world.

Hence with these limitations, further development of KEPS for VCT is necessary for them to become more concrete and to be used by other.
9.4 Possible Future Work

9.2.1 Case Study-1: VCT > Designing > Creativity

**Position-1:** Although, no evidence was gathered relating to the Materials category of 'knowledge’, as well as Moral and Economic aspects in ‘values’ from CS1, the author felt that they were likely to be communicated through VTI. These areas of concern were very intriguing and could have been extended through further investigations in different design areas. However, the decision was made that further in-depth exploration of how the VTI works or how the VCT contributes to the designerly activities and creativity were more important in attaining answers for the research questions. Consequently, further case studies of the links between VCT, creativity and designing were seen as potential areas for future research.

**Position-2:** The links between VCT, designing and creativity in relation to those claims from the literature review that the evidence from CS1 could not support were about ‘imagery helps achieving higher levels of thinking for creativity and problem-solving’. It would probably require an inter-disciplinary team approach to the research, e.g. cognitive psychology, social sciences and design etc. areas of expertise.

**Position-3:** The ID and ED students were shaped through their education to perform different tasks and play different roles in the real practice of the design world. However, the empirical evidence from the CS1 which was supported by views from one of three experts (in materials education for designers) showed that the communication using VTIs was similar between these 2 groups of students. This evidence was supported by the literature review, particularly from the perspectives of historical evidence in the history of technology and engineering (Ferguson, 1993; Weber and Perkin, 1989; Weber at al., 1990; Weber, 1992).
However, evidence from CS1 also showed that the ED students’ perceptions toward VTIs were not as highly appreciative as were the ID students. Moreover, the ED students’ did not admit to the usefulness and helpfulness of VTI, even though they admitted using it for their problem-solving in the case of kite-designing. It could be assumed that the ED group’s responses were about their perceptions and attitudes towards VTIs of the VCT. Therefore, the ED students’ attitudes and perceptions towards reading VTIs, and perhaps in relation to their image as ‘ED’ could be a potential future research area.

9.2.2 Case Study-2: KEPs of VCT

The eye-tracking method in this research study provided objective data that was useful to the analysis of the author’s own practice. In particular, the tracking of the eyes’ scanning paths (the journey that the reading patterns) had generated yielded useful objective data for the traces of the KEPs impacting on the readers’ visual perceptions and understandings. It is possible that this aspect of eye-tracking which is not commonly pursued would also be useful for other research contexts.

9.2.3 Case Study-3: VCT and KEPs in a Richer Context (Materials Technology)

The KEPs have been shown to be effective for communicating technology in the contexts of kite-designing and the communication of materials technology. The KEPs need to be further explored in other design contexts, as well as for other technologies.
References


Blair, A. (1999). In NACCCE (National Advisory Committee on Creative and cultural Education) All our futures. Suffolk: DfEE.


Frayling, C. Practice-based doctorates in the creative and performing arts and design (Warwick, UK: Council for Graduate Education/CEDAR University of Warwick, 1997).


Simmons, P. Exploring website effectiveness and the influence of the Sustainable Design Award website on decision-making concerning sustainability within AS/A2 design and technology (PhD Thesis, Loughborough University, 2010)


Appendices
Talked to Eddie about GRP [glass reinforced plastic] lay-up, since I've not done it before! Have illustrated the basic stages for doing this as a reminder to myself and to be used in design discussions in upcoming days, particularly for gathering comments on how to produce surface textures. I have added notes on vac-forming (using the different types of mould in the GRP process) because I have re-read that the Forex-EPC [special polymer sheet] is suited to vac-forming, despite my earlier workshop trials. So - I am leaving the vac-forming route open, and might well contact a manufacturing company soon to look into making use of it.

Purpose: Explaining things to colleagues

[29.01.98, Project Day 108/227, Diary Entry 229/312, Source: DS51]
"Commentary on DS55. This is an important design sheet to me - I have set out how I think the mass-manufactured guitar will be constructed, for the purposes of talking to Eddie [Norman] and Dick [Heath], so that I can then go on to: (a) make firm recommendations and justifications for the manufacturing route of each component; (b) go ahead and complete the presentation CAD [computer aided design] model, knowing exactly how components will be assembled. I have already had a meeting with Eddie to discuss the ideas on the design sheet - his suggestions are noted on the tracing sheet. We agreed at this meeting that it wouldn't be necessary to provide exact dimensions for the components involved, but rather to communicate the proposed materials, production and assembly details in a joint graphical/text way. After all, final dimensions have not been decided upon... they would be meaningless at this stage."

Purpose: Explaining things to colleagues

[27.04.98, Project Day 143/227, Diary Entry 293/312, Source: DS55]
"Some of the 'checklist' of tech. features on DS3 have been sparked off mentally from previous encounters with 'guitar design' work, others pertain to more 'general' considerations which are appropriate to any product I may be designing."

Purpose: Mementos of ideas coming from existing products

[22.05.96, Project Day 5/227, Diary Entry 11/312, Source: DS03]
"This was clearing up, in my mind, how the build-up of components for the final design was going. I was thinking whilst drawing these that I would need to produce CAD [computer aided design] models of each."

Purpose: Restating design ideas and archiving information

[07.01.98, Project Day 95/227, Diary Entry 195/312, Source: DS43]
"Design sketches of prototype 3 manufacture, for me to visualise what Rob Armstrong was explaining to me. I’ll find it easier to make use of this information in the near future when it’s in illustration rather than memory."

Purpose: Recording ideas and decisions taken at meetings

[21.01.98, Project Day 103/227, Diary Entry 212/312, Source: LB1:49]

"Strengthening ribs on 3D view (experience). Fixing points for moulds (knowledge)."

Purpose: Generating and developing product designs

[17.10.96, Project Day 19/227, Diary Entry 55/312, Source: DS23]
"All the while whilst on DS45 I knew that I would be working with 8mm depth polycarbonate and that the bridge would be machined using CNC [computer numerically controlled] methods because of the intricate/precise curves required. When working on the right-most drawing (marked 'X') I had in my mind an image of a block being machined to produce the shape I wanted - using the Department's Workshop 1 machines. I found myself 'extending profile lines' as if they were paths for the milling cutters to follow. I also imagined the milling machine producing the overall edge shape, 1mm or so a time. I concluded that the whole component could be produced on the CNC machines, save a few operations which cannot be performed in 2.5-D machining."

Purpose: Generating and developing product designs

[22.01.98, Project Day 104/227, Diary Entry 214/312, Source: DS45]
"When I placed the shell against my table (reasonably dark wood) it confirmed in my mind (and what I'd drawn on DS51) that I'd like the neck and head to be manufactured from very light coloured wood. It looked too dingy and furniture-like with the darker wood."

Purpose: Generating and developing product designs

[15.07.98, Project Day 173/227, Diary Entry 306/312, Source: DS51]
Appendix 2.2 (1/4)

Drawings and other models used in the development of a pyrotechnic spectacle by World Famous. Full Circle was first seen in Falkirk and has since been shown in London and Turin. The story line of the show follows the unfolding of the seasons marked out and symbolized by synthesized and live music, ????? of flame, smoke, changing lights, a blazing symbolic tree and extraordinary pyrotechnics.

FULL CIRCLE credits

A collaboration between The World Famous (directed by Mike Roberts) and the Slovenian band Terrafolk. Full Circle is an IN SITU show. IN SITU is a European network for artistic creation in public areas financed with the support of the European Commission. Full Circle was commissioned by the Big in Falkirk Festival and IN SITU and co-commissioned by Without Walls.

Initial design sketches by Mandy Dike
Appendix 2.2 (2/4)

Technical drawings for the pods by Graeme Gilmour

The World Famous
Full Circle Pod
Side Elevation
Scale 1: 25mm
Appendix 2.2 (3/4)
ALLOWING A LANGUAGE OF FORM TO DEVELOP

The question was: what form should the building take? The City Palace Tower clearly needed to be something more than functional. Could the form of the building somehow represent the idea of marriage? The double helix familiar from genetics came to symbolize the idea of union. Drawing proved to be the perfect way to explore this interaction between form and meaning. Sketches could quickly give shape to ideas about natural forms and building structures. The fact that they were quick to do – a kind of shorthand – helped to stimulate creative thinking.
THE IDEA FOR THE BUILDING DEVELOPED THROUGH DRAWINGS WHICH SYNTHESIZED THE DIVERSE FORMS

The origins of the final design can be clearly seen in these exploratory sketches. The architects thought of the tower as though it was a drawing! “The organic form of the tower is a beautiful linear drawing in three dimensions.”

PLACE

“In Moscow, the City Palace Tower will not only contribute to the architectural dynamic of the city, it will add to its poetic and cultural dimensions.”

Using CGI – computer generated images – it is possible for architects to give extraordinary reality to their proposals for future buildings and environments.

A fine 3-D model was also used to show how the building would appear as a form in space.
Appendix 2.3 (3/6)
ELEGANT AND SENSUOUS – A LINEAR DRAWING IN THREE DIMENSIONS

*The formal spiral round the core links back to the chemical structure of DNA as well as the intertwining of two figures. The nature of DNA providing a fused genetic inheritance linking us back to the past and forward into the future:

Digital drawings take the concept forward from the initial sketches into more detail. This process continues as the design of more and more elements in the building are resolved.
Appendix 2.3
Appendix 2.3

HOW WILL IT BE?

Computer simulations allow the architects to imagine and 'make visible' the proposed interiors complete with realistic people and the activities of everyday life. Doing this helps the architects as much as their clients and future users of the building.
### Visual Samples from Tufte’s Principles and Techniques for Graphical Practice

*(Tufte 1990; 2004; 2006)*

**Appendix 2.4(1/3)**

<table>
<thead>
<tr>
<th>NO.</th>
<th>PRINCIPLES/TECHNIQUES</th>
<th>VISUAL EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Escaping flatland; also</td>
<td><img src="image1.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; integrate statistical and verbal descriptions into data set</td>
<td><img src="image2.png" alt="Example" /></td>
</tr>
<tr>
<td>2.</td>
<td>Micro/Macro readings of details; also</td>
<td><img src="image3.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; induce viewers to think of substance; not the others (e.g. graphics)</td>
<td><img src="image4.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; Present many numbers in a small space</td>
<td><img src="image5.png" alt="Example" /></td>
</tr>
<tr>
<td>3.</td>
<td>Layering and separation of data; also</td>
<td><img src="image6.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; display/show the data or specification;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; Reveal data at several levels of details;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; encourage comparison of data</td>
<td></td>
</tr>
</tbody>
</table>
### Visual Samples from Tufte’s Principles and Techniques for Graphical Practice

* (Tufte 1990; 2004; 2006)

#### Appendix 2.4 (2/3)

<table>
<thead>
<tr>
<th>NO.</th>
<th>PRINCIPLES/TECHNIQUES</th>
<th>VISUAL EXAMPLES</th>
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</thead>
<tbody>
<tr>
<td>4.</td>
<td>Small multiples; also</td>
<td><img src="image1.png" alt="Visual Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; encourage comparison of data;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; integrate statistical and verbal descriptions into data set</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Colour and information</td>
<td><img src="image2.png" alt="Visual Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; Reveal data at several levels of details;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; encourage comparison of data</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Narrative of space and times; also</td>
<td><img src="image3.png" alt="Visual Example" /></td>
</tr>
<tr>
<td></td>
<td>&gt; avoid distorting the facts;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; make the data set coherent;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; serve a reasonably clear purpose;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; encourage comparison of data;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; Reveal data at several levels of details to a fine structure;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; integrate statistical and verbal descriptions into data set</td>
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</tr>
<tr>
<td>NO.</td>
<td>PRINCIPLES/TECHNIQUES</td>
<td>VISUAL EXAMPLES</td>
</tr>
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<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7.</td>
<td>Sparklines</td>
<td><img src="image1.png" alt="Sparklines Example" /></td>
</tr>
<tr>
<td>8.</td>
<td>Links and causal arrows</td>
<td><img src="image2.png" alt="Causal Arrows Example" /></td>
</tr>
<tr>
<td>9.</td>
<td>Coherence of words, numbers and images; also</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; make the data set coherent</td>
<td><img src="image3.png" alt="Coherence Example" /></td>
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</tbody>
</table>

Visual Samples from Tufte’s Principles and Techniques for Graphical Practice
*(Tufte 1990; 2004; 2006)*

Appendix 2.4 (3/3)
Appendix 5.1(1/2)

**Induction Day 25 Sept 2009**

Department of Design & Technology
Loughborough University

**Modelling a Miniature Kite Design**

**Description**

Produce a miniature kite to represent your **first impression** of Loughborough.

Various types of kite information are available, either in this brief or on the Flight Deck.

You will be working in groups.

**Design Limitations**

- No dimension larger than A5 (*can be as small as 2”*)
- From any or a combination of the materials provided
- Any shape or form

**Other Limitation**

- To fly the kite indoors

**Useful Websites**


[remember to see Lin video & Glenn movie]
Appendix 5.1 (2/2)

Exercise & Experiment
## Appendix 5.2 (1/2)

<table>
<thead>
<tr>
<th>EXISTING SAMPLES IN MARKET</th>
<th>STUDENTS KITE DESIGNS (Levels of Creativity)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1) LDS Induction Day Group</td>
</tr>
<tr>
<td></td>
<td>little 'c'</td>
</tr>
<tr>
<td></td>
<td>Big 'C'</td>
</tr>
<tr>
<td></td>
<td>(2) Validation Group (LDS PGCE)</td>
</tr>
<tr>
<td></td>
<td>little 'c'</td>
</tr>
<tr>
<td></td>
<td>Big 'C'</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>LDS Induction Day Group</th>
<th>Validation Group (LDS PGCE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

- **Identical**
- little 'c'
- Big 'C'

- **Identical**
- little 'c'
- Big 'C'
# Appendix 5.2

## Existing Samples in Market

### Students Kite Designs

<table>
<thead>
<tr>
<th>EXISTING SAMPLES IN MARKET</th>
<th>STUDENTS KITE DESIGNS (Levels of Creativity)</th>
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<tbody>
<tr>
<td></td>
<td>Group-1</td>
</tr>
<tr>
<td></td>
<td>little 'c'</td>
</tr>
<tr>
<td></td>
<td>Identical</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**Legend:**

- **Identical** to the existing kites (non-creative)
- **little 'c'** kites = Archetypes (less creative)
- **Big 'C'** kites = Historicist (more creative)
- **X** = Cannot Fly
Appendix 5.3

Miniature Kite Design Brief

Description

Produce a miniature kite – introducing Pasir Gudang International Kite Festival or representing Malaysian culture and heritage for promoting Malaysia tourism.

Required Outcomes:

1. Visual communication activities & questionnaire forms.
2. Sketches or annotated drawings of your kite designs.
3. Kite photograph (as the best image to promote your product)
4. Kite in action (a video clip; maximum 30 sec.)

Design Limitations

- No dimension larger than A5 (14.8cm X 21cm X 14.8cm); or can be as small as 2”.
- From any or a combination of the materials available.
- Any shape or form.

Important Notes:

Hand in items 1 – 4 at submission desk at the end of the session.

Other Limitation

- To fly the kite indoors

Useful Websites

Appendix 6.1

ETHICAL ADVISORY COMMITTEE

Ethical Clearance Checklist
(TO BE COMPLETED FOR ALL INVESTIGATIONS INVOLVING HUMAN PARTICIPANTS)

If your research is being conducted off-campus and ethical approval has been granted by an external ethics committee, you may not need to seek full approval from the University Ethical Advisory Committee. However you will be expected to provide evidence of approval and the terms on which this approval has been granted.

If you believe this statement applies to your research, please contact the Secretary of the Ethical Advisory Committee for confirmation.

If your research is transferring into Loughborough University and approval was obtained from your originating institution, there is a requirement on the University to ensure that appropriate approvals are in place.

If you believe this statement applies to your research, please contact the Secretary of the Ethical Advisory Committee with evidence of former approval and the terms on which this approval has been granted.

It is the responsibility of the individual investigators to ensure that there is appropriate insurance cover for their investigation.

If you are at all unsure about whether or not your study is covered, please contact the Finance Office to check.

Section A: Investigators

Title of Investigation
Visual Communication of Technology

Name, Status and Email Address of Senior Investigators (University Staff Research Grade II and above):
(Please underline responsible investigator where appropriate)
Professor Eddie Norman, Main Supervisor, E.W.Norman@lboro.ac.uk; Kevin Badni, 2nd Supervisor, K.S.Badni@lboro.ac.uk.

Department: Design and Technology

Name, Status and Email Address of Other Investigators (other University Staff and Students):
Cheng-Siew Beh, PhD Research Student, C.S.Beh@lboro.ac.uk

Department: Design and Technology

October 2008
Appendix 6.1 (2/7)

A1. Do investigators have previous experience of, and/or adequate training in, the methods employed?
   Yes √ No □ If No, Please provide details below

A2. Will junior researchers/students be under the direct supervision of an experienced member of staff?
   Yes √ No □ If No, Please provide details below

A3. Will junior researchers/students be expected to undertake physically invasive procedures (not covered by a generic protocol) during the course of the research?
   Yes* □ No √ If Yes, Please provide details below

A4. Are researchers in a position of direct authority with regard to participants (e.g., academic staff using student participants, sports coaches using his/her athletes in training)?
   Yes* □ No √ If Yes, Please provide details below

If you have selected one of the answers above marked with an * please provide additional information on how you intend to manage the issues (please continue onto a separate sheet if required), then submit this checklist to the Secretary to the EAC:

Section B: Participants

Vulnerable Groups
Will participants be knowingly recruited from one or more of the following vulnerable groups?

B1. Children under 18 years of age
   Yes* □ No √
   (please refer to published guidelines)

B2. People over 65 years of age
   Yes* □ No √

B3. Pregnant women
   Yes* □ No √

B4. People with mental illness
   Yes* □ No √

B5. Prisoners/Detained persons
   Yes* □ No √

B6. Other vulnerable group (please specify )
   Yes* □ No √

# If the procedure is covered by an existing generic protocol which refers specifically to the vulnerable group(s), please insert reference number here

If the procedure is not covered by an existing generic protocol, please submit a full application to the Ethical Advisory Committee

Chaperoning Participants

October 2008
Appendix 6.1(3/7)

Page 3 of 7

If appropriate, e.g. studies which involve vulnerable participants, taking physical measures or intrusion of participants' privacy:

B7. Will participants be chaperoned by more than one investigator at all times?

Yes ☐ No* ☐ N/A 1[ ]

If N/A, please provide details below.

B8. Will at least one investigator of the same sex as the participant(s) be present throughout the investigation?

Yes ☐ No* ☐ N/A

If N/A, please provide details below.

B9. Will participants be visited at home?

Yes* ☐ No ☐ N/A

If N/A, please provide details below.

The experiment will be conducted at the university.

* Please submit a full application to the Ethical Advisory Committee.

If you have selected one of the answers above marked with an * please provide additional information on how you intend to manage the issues (please continue onto a separate sheet if required), then submit this checklist to the Secretary to the EAC:

Section C: Methodology/Procedures

To the best of your knowledge, please indicate whether the proposed study:

C1. Involves taking bodily samples

Yes* ☐ No ☐

(please refer to published guidelines)

C2. Involves procedures which are likely to cause physical, psychological, social or emotional distress to participants

Yes* ☐ No ☐

C3. Is designed to be challenging physically or psychologically in any way (includes any study involving physical exercise)

Yes* ☐ No ☐

# If the procedure is covered by an existing generic protocol, please insert reference number here

If the procedure is not covered by an existing generic protocol, please submit a full application to the Ethical Advisory Committee

C4. Exposes participants to risks or distress greater than those encountered in their normal lifestyle

Yes* ☐ No ☐

C5. Involves collection of body secretions by invasive methods

Yes* ☐ No ☐

C6. Prescribes intake of compounds additional to daily diet or other dietary manipulation/supplementation

Yes* ☐ No ☐

C7. Involves testing new equipment

Yes* ☐ No ☐

C8. Involves pharmaceutical drugs

Yes* ☐ No ☐
Appendix 6.1

C9. Involves use of radiation
   (please refer to published guidelines)
   
   Yes* ☐ No ☑

C10. Involves use of hazardous materials
   (please refer to published guidelines)
   
   Yes* ☐ No ☑

C11. Assists/alters the process of conception in any way
   
   Yes* ☐ No ☑

C12. Involves methods of contraception
   
   Yes* ☐ No ☑

C13. Involves genetic engineering
   
   Yes* ☐ No ☑

* If you have answered ‘Yes’ to any of the above please submit a full application to the Ethical Advisory Committee.

Section D: Observation/Recording

D1. Does the study involve observation and/or recording of participants?

   Yes ☑ No ☐
   If No, please go to Section E

If Yes,

D2. Will those being observed and/or recorded be informed that the observation and/or recording will take place?
   
   Yes ☑ No* ☐

* Please submit a full application to the Ethical Advisory Committee.

Section E: Consent and Deception

E1. Will participants give informed consent freely?
   
   Yes ☑
   If yes please complete the Informed Consent section below.

   No* ☐
   *If no, please submit a full application to the Ethical Advisory Committee.

   Note: where it is impractical to gain individual consent from every participant, it is acceptable to allow individual participants to “opt out” rather than “opt in”.

   Informed Consent

   E2. Will participants be fully informed of the objectives of the investigation and all details disclosed (preferably at the start of the study but where this would interfere with the study, at the end)?
   
   Yes ☑

   No* ☐

   E3. Will participants be fully informed of the use of the data collected (including, where applicable, any intellectual property arising from the research)?
   
   Yes ☑

   No* ☐

E4. For children under the age of 18 or participants who have impairment of understanding or communication:
- will consent be obtained (either in writing or by some other means)?

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Appendix 6.1

- Will consent be obtained from parents or other suitable person?  
  Yes ☐  No* ☐  N/A ✓

- Will they be informed that they have the right to withdraw regardless of parental/guardian consent?  
  Yes ☐  No* ☐  N/A ✓

E5. For investigations conducted in schools, will approval be gained in advance from the Head-teacher and/or the Director of Education of the appropriate Local Education Authority?  
  Yes ☐  No* ☐  N/A ✓

E6. For detained persons, members of the armed forces, employees, students and other persons judged to be under duress, will care be taken over gaining freely informed consent?  
  Yes ☐  No* ☐  N/A ✓

* Please submit a full application to the Ethical Advisory Committee

Deception

E7. Does the study involve deception of participants (i.e. withholding of information or the misleading of participants) which could potentially harm or exploit participants?  
  Yes ☐  No* ☐  If No, please go to Section F

If yes,

E8. Is deception an unavoidable part of the study?  
  Yes ☐  No* ☐

E9. Will participants be de-briefed and the true object of the research revealed at the earliest stage upon completion of the study?  
  Yes ☐  No* ☐

E10. Has consideration been given on the way that participants will react to the withholding of information or deliberate deception?  
  Yes ☐  No* ☐

* Please submit a full application to the Ethical Advisory Committee

Section F: Withdrawal

F1. Will participants be informed of their right to withdraw from the investigation at any time and to require their own data to be destroyed?  
  Yes ✓  No* ☐

* Please submit a full application to the Ethical Advisory Committee

Section G: Storage of Data and Confidentiality

Please see University guidance on Data Collection and Storage.

G1. Will all information on participants be treated as confidential and not identifiable unless agreed otherwise in advance, and subject to the requirements of law?  
  Yes ✓  No* ☐

G2. Will storage of data comply with the Data Protection Act 1998?
Appendix 6.1

Page 6 of 7

(Please refer to published guidelines)

G3. Will any video/audio recording of participants be kept in a secure place and not released for use by third parties? Yes ☐ No* ☐

G4. Will video/audio recordings be destroyed within six years of the completion of the investigation? Yes ☒ No* ☐

G5. Will full details regarding the storage and disposal of any human tissue samples be communicated to the participants? N/A ☑ Yes ☒ No* ☐

* Please submit a full application to the Ethical Advisory Committee

Section H: Incentives

H1. Have incentives (other than those contractually agreed, salaries or basic expenses) been offered to the investigator to conduct the investigation? Yes* ☐ No ☒ "If Yes, Please provide details below"

H2. Will incentives (other than basic expenses) be offered to potential participants as an inducement to participate in the investigation? Yes* ☐ No ☒ "If Yes, Please provide details below"

If you have selected one of the answers above marked with an * please provide additional information on how you intend to manage the issues (please continue onto a separate sheet if required), then submit this checklist to the Secretary to the EAC:

Section I: Work Outside of the United Kingdom

G1. Is your research being conducted outside of the United Kingdom? Yes ☐ No ☒

If Yes, you may need additional insurance cover/clearance for your research.

If, having completed this checklist, you will be making a full application to the EAC, this issue will be checked for you as a part of the process. If however you do not need to complete a full application please contact Hiten Patel (H.Patel@boro.ac.uk).

Section I: Declarations

Checklist Application only:

If you have completed the checklist to the best of your knowledge without selecting an answer marked with an * or †, your investigation is deemed to conform with the ethical checkpoints and you do not need to seek formal approval from the University's Ethical Advisory Committee. Please sign the declaration below, and lodge the completed checklist with your Head of Department or his/her nominee.

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Appendix 6.1

Declaration
I have read the University's Code of Practice on Investigations on Human Participants. I confirm that the above named investigation complies with published codes of conduct, ethical principles and guidelines of professional bodies associated with my research discipline.

Checklist with additional information to the Committee:
If, upon completion of the checklist you have ONLY selected answers which require additional information to be submitted with this checklist (indicated by a †), please ensure that all the information is provided in detail and send this checklist to the Secretary to the EAC.

Full Application Needed:
If on completion of the checklist you have selected one or more answers which require the submission of a full proposal please download the relevant form from the Committee's web page.
A copy of this checklist, signed by your Head of Department should accompany the full submission to the Ethical Advisory Committee.

Signature of Responsible Investigator

Signature of Student (if appropriate)

Signature of Head of Department or his/her nominee

Date

Advice to Participants following the investigation

Investigators have a duty of care to participants.

When planning research, investigators should consider what, if any, arrangements are needed to inform participants (or those legally responsible for the participants) of any health related (or other) problems previously unrecognised in the participant. This is particularly important if it is believed that by not doing so the participants well being is endangered. Investigators should consider whether or not it is appropriate to recommend that participants (or those legally responsible for the participants) seek qualified professional advice, but should not offer this advice personally. Investigators should familiarise themselves with the guidelines of professional bodies associated with their research.
Appendix 6.2 (1/2)

**Visual Communication of Technology: PhD Research by Cheng-Siew Beh**

**Briefing**

This study is intended to gather viewers' reading patterns on visual information. A series of representations (6 visuals in total) will be shown for scanning. The scanning process will be recorded for capturing individuals' visual reading patterns, while testing the principles of visual communication applied on those representations.

The 6 visuals are put into 3 sets for study; they are:
1. Visuals without language explanation;
2. Visuals with language explanation (accompanied by captions and interview prompts);
3. Visuals placed in 3 pairs for comparison.

This visual test only requires the viewers to respond to what they have seen and describe what they have understood from the visuals.

**Notes:**

- The recording system involves a small camera device and an audio recorder. Audio will record the interview prompts and responses; whilst, the camera is attached to a bicycle helmet which will be put on the viewer, and will be calibrated according to every individual's eyes.
- During the calibration procedure, viewers are required to keep their head still and stare at a point before being asked to move to looking at the next point.
- All recordings either visual or audio are only for research data analysis, and the recordings will not be published. These data will be held securely until the end of the research project and then destroyed in keeping with ethical practices.
- Participants will be anonymous in all published outcomes.
- Some personal details will be gathered for research data, particularly the viewers' academic background, prior knowledge, cultural background, age and gender groups, as these factors may or may not influence the research data.

<table>
<thead>
<tr>
<th>Personal Details:</th>
<th>Use of audio for thesis/papers/presentations:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>ALLOW</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1. Name:</th>
<th>(In case the research analysis needs clarification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Gender:</td>
<td>M</td>
</tr>
<tr>
<td>3. Age:</td>
<td>18 - 25</td>
</tr>
<tr>
<td>4. Which country did you spend most time when you were growing up:</td>
<td></td>
</tr>
<tr>
<td>5. Programme/Course:</td>
<td></td>
</tr>
<tr>
<td>6. Prior Experience, particularly relating to visual education: (e.g. GCSE, AS/A2 Levels, Foundation Courses in Art, D&amp;C, Pastimes in Art, Photography, etc.)</td>
<td></td>
</tr>
<tr>
<td>7. What is your preferred learning style: (Choose one that is most relevant to you)</td>
<td>Visual</td>
</tr>
<tr>
<td>8. Email address:</td>
<td>(In case the research analysis needs clarification)</td>
</tr>
</tbody>
</table>
Appendix 6.2 (2/2)

Loughborough University

Insert Name of Research Proposal

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name

Your signature

Signature of investigator

Date
**Visual Communication Of Technological Information**  
In Materials Selection For Industrial And Engineering Design  
- PhD Research by Cheng-Siew Teh -

**Introduction**
This study is intended to gather data concerning reading preferences, perceptions and interpretation of visual information; in particular, within the context of materials technology. A series of visual representations of materials selection information is shown in the following questionnaire.

Some personal background details are asked for in this research questionnaire, such as the respondents’ name and email address (both optional), academic background/prior knowledge, cultural background, age and gender groups. This is intended just for research data, as these factors may or may not influence the findings. Respondents will be anonymous in all published outcomes.

**SECTION A: Personal/Background Information**

1. Name (optional):
2. Gender: Male/Female
4. Country of growing up:
5. Programmes/Courses currently studied:
6. Prior Experience, relating to visual education: yes/No

**SECTION B: Disposition towards Visual Information**

1. Which types of visual tools are those that you use most often in your work? (circle those relevant to you)
   - **ICONIC:** Sketch; Drawing; Illustration; 2D/3D Model; Product Photograph; Technical Drawing
   - **SYMBOLIC:** Symbolic; Pie Chart; Bar Chart; Mathematical Formula; Graph; Diagrams; Visual Matrix as shown below:
   - **ANALOGUE:** Storyboard; Map; Annotation; Exploded; Dialogue Bars; Flowchart; Table

2. By comparing the visual representations above, answer the following questions from 2.1 until 2.6:
   2.1 What is the key message that the visuals H and I imply?
   
   2.2 How valuable is the message in 2.1 to you in designing? (circle one only)

   2.3 By comparing visuals H and I, which one do you find is more effective in conveying its message? (circle one only)

   2.4 Which features catch your attention in the visual of your choice in 2.3? (Please state them in order if possible)

   2.5 Which features of the visual of your choice in 2.3 or 2.4 are key to enabling your understanding?

   2.6 Do you have any other comments on these visuals?
3. By comparing the visual representations on the left, answer the subsequent questions from 3.1 until 3.7.

3.1 What is the key message that the visuals B and C imply?

3.2 Visual A has a slightly different message than visuals B and C, what is it?

3.3 How valuable is the message in 3.1 or 3.2 to your designing? (1 one only)

<table>
<thead>
<tr>
<th>Not Important</th>
<th>Semi Importance</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
</table>

3.4 By comparing visuals B and C, which one do you find is more effective in conveying its message? (1 one only)

Visual B
Visual C

3.5 Which features catch your attention in the visual of your choice in 3.6? (Please state them in order if possible)

3.6 Which features of the visual of your choice in 3.4 or 3.5 are key to enabling your understanding?

3.7 Do you have any other comments on these visuals?
4. By comparing the visual representations on the left, answer the subsequent questions from 4.1 until 4.6:
4.1 What is the key information that visuals D and E have in common? 

4.2 How valuable is the information in 4.1 to your designing? (1 one only)

<table>
<thead>
<tr>
<th>Not Important</th>
<th>Somewhat Important</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
</table>

4.3 By comparing visuals D and E, which one do you find is more effective in conveying its information? (1 one only)

<table>
<thead>
<tr>
<th>Visual D</th>
<th>Visual E</th>
</tr>
</thead>
</table>

4.4 Which features catch your attention in the visual of your choice in 4.3? (Please state them in order if possible)

4.5 Which features of the visual of your choice in 4.3 or 4.4 are key to enabling your understanding?

4.6 Do you have any other comment on these visuals?

----------------------------------------------------------------------------------------------------------------------------------
5.1 What is the key message that the visuals F and G imply?

5.2 How valuable is the message in 5.1 to your designing? (1 one only)

<table>
<thead>
<tr>
<th>Least Important</th>
<th>Some Importance</th>
<th>Important</th>
<th>Very Important</th>
</tr>
</thead>
</table>

5.3 By comparing visuals F and G, which one do you find is more effective in conveying its message? (1 one only)

<table>
<thead>
<tr>
<th>Visual F</th>
<th>Visual G</th>
</tr>
</thead>
</table>

5.4 Which features catch your attention in the visual of your choice in 5.3? (Please state them in order if possible)

5.5 Which features of the visual of your choice in 5.3 or 5.4 are key to enabling your understanding?

5.6 Do you have any other comment on these visuals?
6. By comparing the visual representations on the left, answer the subsequent questions from 6.1 until 6.6:

6.1 What is the key information that visuals J and K depict?

6.2 How valuable is the information in 6.1 to your designing? (1-5 only)

6.3 By comparing visuals J and K, which one do you find is more effective in conveying its information? (1-5 only)

6.4 Which features catch your attention in the visual of your choice in 6.3? (Please state them in order if possible)

6.5 Which features of the visual of your choice in 6.3 or 6.4 are key to enabling your understanding?

6.6 Do you have any other comments on these visuals?
Thank you for your time in completing the questionnaires.

Please send the completed questionnaires to c.s.beh@lboro.ac.uk

References


Appendix 7.2

Visual Communication Of Technology:
The recently recognised importance of
sensorial properties of materials

cheng-siew leh
Supervised by Eddie Norman and Kevin Badni

Introduction

Strong feature of technology practice for centuries:

Latchet device, da Vinci, 1500 (Ferguson 1993)
Appendix 7.2 (2/6)

This research seeks...

To understand the principles behind the Visual Communication of Technology (VCT).

Key emerging principles (KEPs) of VCT

1. Facilitating COMPARISON to reveal RELATIONSHIP:

Tufte; Rand; Ferguson; Thomson

Manual sawmill, Besançon, 1578
(Ferguson 1993)
Appendix 7.2 (3/6)

Key emerging principles (KEPs) of VCT

2. Unity of FORM to accentuate FUNCTION:

Tufte; Rand; Ferguson; Thomson

Nomogram, Maurice d’Ocagne, 1862
(Ferguson 1993)

3. Precision of DATA to communicate the TRUTH:

Tufte; Rand; Ferguson; Thomson

The terrible fate of Napoleon’s army
march to Moscow, Minard 1861
(Tufte 1983/2002)
Appendix 7.2

Key emerging principles (KEPs) of VCT

4. SIMPLE in design form; COMPLEX in carrying data:

KEPs of VCT being explored via eye-tracking

Eye-tracking device setup
Appendix 7.2 (5/6)

Eye-tracking raw data

Participant’s reading scanpath:

video clip

Eye-tracking results
Now the research is exploring...

Visual communication of materials technology in relation to the importance of sensorial properties of materials.

Material Languages. Pedgley (2010)

* KEPS have been applied in the redesign of representations

Your helps are greatly appreciated...

Please complete the questionnaires

~ your views are very important to this research ~

do feel free to detach the final page of the questionnaire for references to this area

c.s.beh@lboro.ac.uk
Appendix 7.3

Visual Communication Of Technology (VCT):
Visual technological information (VTI) used for materials technology (ID vs. ED)

Supervised by Eddie Norman and Kevin Badni

Presentation Overview

- Introduction of the study
- Key findings from the ID & ED books analysis
- Context and key aspects of the VTI questionnaire survey
- Survey results
- Discussion questions
Appendix 7.3 (2/9)

Introduction of the study

1. Book Analysis
   - ID Book: Ashby & Johnson 2004
   - ED Book: Ashby 2005

2. VTI Questionnaire
   
3. Discussions with Materials Experts

Books Analysis

- Key aspects to analyse the ID & ED books:
  - Types of Models: used
    - Baynes, 2009
  - Graphical Strategies: used
    - Danos, 2009
  - Graphical Techniques: applied
    - Tuito, 1999-2009
  - KEPs of VCT: applied
    - Bels & Normah, 2009

cheng-siew leb
Appendix 7.3 (3/9)

VTI Survey Context

Comparison of understanding & effective visuals:

<table>
<thead>
<tr>
<th>Existing/ED visuals</th>
<th>vs.</th>
<th>Redesigned/ID visuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>masters level</td>
<td></td>
<td>undergraduate level</td>
</tr>
</tbody>
</table>

Cultural differences:

<table>
<thead>
<tr>
<th>ED students</th>
<th>vs.</th>
<th>ID students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Country</td>
<td></td>
<td>Eastern Country</td>
</tr>
</tbody>
</table>

VTI Survey Focus

Key aspects of the VTI questionnaire survey:

- Understanding of key message
- Features that caught the attention
- Features that enabled understanding of key message

Effective Visual
Appendix 7.3 (5/9)

Survey Results: Question-4 (Pair-3)

<table>
<thead>
<tr>
<th>ID (Master)</th>
<th>ED (Undergrads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDS</td>
<td>METU</td>
</tr>
<tr>
<td>1 vs 9</td>
<td>0 vs 12</td>
</tr>
<tr>
<td>LDS</td>
<td>PJB</td>
</tr>
<tr>
<td>1 vs 5</td>
<td>7 vs 12</td>
</tr>
</tbody>
</table>

Understanding: 19/44, Effective Visual: 81/74

Survey Results: Question-5 (Pair-4)

<table>
<thead>
<tr>
<th>ID (Master)</th>
<th>ED (Undergrads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDS</td>
<td>METU</td>
</tr>
<tr>
<td>5 vs 5</td>
<td>6 vs 6</td>
</tr>
<tr>
<td>LDS</td>
<td>PJB</td>
</tr>
<tr>
<td>1 vs 4</td>
<td>1 vs 18</td>
</tr>
</tbody>
</table>

Understanding: 30/46, Effective Visual: 70/67
Appendix 7.3 (7/9)

Survey Results: Summary

- Comparison of numerical data between LDS and METU; and PJB and LDS
- Comparison of the selection of effective VTI between Existing and Redesigned

Table 7.26
Summary of the VTI Questionnaire Survey Results: Comparison of Numerical Data between LDS and METU; and PJB and LDS

<table>
<thead>
<tr>
<th>Question (Q)</th>
<th>LDS (40 1st Year Students)</th>
<th>METU (12 1st Year Students)</th>
<th>PJB (19 ED Diploma Students)</th>
<th>LDS (6 ED/R6 Students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q7 (Figure 7.17)</td>
<td>1 vs. 7 (2 did not answer)</td>
<td>6 vs. 6</td>
<td>3 vs. 16</td>
<td>3 vs. 5</td>
</tr>
<tr>
<td>Q3 (Figure 7.18)</td>
<td>0 vs. 19</td>
<td>3 vs. 9</td>
<td>0 vs. 19</td>
<td>1 vs. 5</td>
</tr>
<tr>
<td>Q4 (Figure 7.19)</td>
<td>1 vs. 9</td>
<td>0 vs. 12</td>
<td>7 vs. 12</td>
<td>1 vs. 5</td>
</tr>
<tr>
<td>Q5 (Figure 7.20)</td>
<td>5 vs. 5</td>
<td>6 vs. 6</td>
<td>1 vs. 10</td>
<td>1 vs. 4 (1 did not answer)</td>
</tr>
<tr>
<td>Q6 (Figure 7.21)</td>
<td>5 vs. 5</td>
<td>4 vs. 8</td>
<td>6 vs. 13</td>
<td>2 vs. 4</td>
</tr>
<tr>
<td>Q7 (Figure 7.22)</td>
<td>1 vs. 9</td>
<td>2 vs. 30</td>
<td>4 vs. 24 (1 did not answer)</td>
<td>2 vs. 3 (1 did not answer)</td>
</tr>
</tbody>
</table>
Appendix 7.3

Table 7.17
Summary of the VTI Questionnaire Survey Results: Comparison of the Selection of Effective VTI between Existing/ED and Redesigned/ID VTI

<table>
<thead>
<tr>
<th>Question (Q)</th>
<th>Existing VTI; or ED Visual</th>
<th>Redesigned VTI; or ID Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Understanding</td>
<td>Effective Visual</td>
</tr>
<tr>
<td>Q2 (Figure 7.17)</td>
<td>54%</td>
<td>28%</td>
</tr>
<tr>
<td>Q3 (Figure 7.18)</td>
<td>100%</td>
<td>9%</td>
</tr>
<tr>
<td>Q4 (Figure 7.19)</td>
<td>44%</td>
<td>19%</td>
</tr>
<tr>
<td>Q5 (Figure 7.20)</td>
<td>46%</td>
<td>30%</td>
</tr>
<tr>
<td>Q6 (Figure 7.21)</td>
<td>35%</td>
<td>36%</td>
</tr>
<tr>
<td>Q7 (Figure 7.22)</td>
<td>33%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Key findings of the study

- Different types of representational models used.
- Different graphical strategies used.
- Similar graphical techniques applied.
- Similar KEPs of VCT applied, but not completely successful.
- Redesigned VTIs were more effective visually to get attention and communicating the messages.
- No difference of understanding and visual effectiveness in VTI between ID and ED students, or for cultural background.
- Some evidence of educational level affecting understanding and visual effectiveness.
Appendix 7.3

Questions

- Do you think ID and ED students need different styles of VTI to understand information concerning materials?
  - Relating to the representational models used?
  - Relating to graphical strategies and techniques?
- Were the results presented as you would have expected?
  - Would you expect there to be different principles (KEPs) that applied to ID and ED students?
- Did you expect to see that there was no evidence of cultural differences influencing understanding of VTI (or VCT)?

Thank You

c.s.beh@lboro.ac.uk
Annexes
Annexes (only available by request to the author)

Kite-workshop in UK
- Kite-Poster Questionnaire
- Kite Assessment Form
- Paired Comparison Slides
- Kite Exercise
- Discussion Slides

Kite-workshop in Malaysia
- Kite-Poster Questionnaire
- Students Kite Report Form
- Paired Comparison Slides

Materials Technology Survey in Malaysia
- Students Questionnaire – Diagram-1
- Students Questionnaire – Diagram-2
- ID Lecturer Questionnaire
- ED Lecturer Questionnaire
- Courseware Team Questionnaire

Pilot Eye-tracking on Blue-Kite-Poster
- P1-Reading Blue Kite-Poster(Video and Raw Source Files)
- P2-Reading Blue Kite-Poster(Video and Raw Source Files)
- P3-Reading Blue Kite-Poster(Video and Raw Source Files)
- P1 to P3 Reading Sequence Chart

Case Study-2: Validation Analysis and Raw Sources
- P1-Scanpaths (Visuals A to F including: raw video and audio files, scanpaths clips, and captured individual scenes)
- P2-Scanpaths (Visuals A to F including: raw video and audio files, scanpaths clips, and captured individual scenes)
- P3-Scanpaths (Visuals A to F including: raw video and audio files, scanpaths clips, and captured individual scenes)
- P4-Raw Video and Audio files (including: Visuals A to F)
- P5-Raw Video and Audio files (including: Visuals A to F)
- P1 to P3 Sequence Charts (Visuals C to F)

Case Study-3 Validation Discussion with Material Expert – Dr. Houzheng Wu, Materials Department, LU, UK (Audio File)