Developing Sketching Expertise within Technology Education

A thesis submitted to the University of Limerick for the degree of Doctor of Philosophy

by

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Declaration

I declare that this thesis has not already been accepted in substance for any degree and is not being submitted in candidature for any degree.

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Date         Date

Statement

I affirm that the substance of this thesis is entirely the result of my own investigation and that due reference and acknowledgement is made where necessary to the work of other researchers.

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Date         Date
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Abstract

At a time when technological capabilities are perceived to be critical in redefining effective technological education, the introduction of Design and Communication Graphics (DCG) in Irish second level (high) schools has broad implications. Students now have the potential to explore applied geometries, integrated with conceptual thinking in addition to developing essential communication skills. Central to this development is the ability to freehand sketch.

Literature concerning freehand sketching (Verstijnen, 1998b) claims that there is a lack of empirically validated models of instruction which promote the development of sketching ability. This research study set out to explore if it was possible to develop the ability to freehand sketch through appropriate instruction and empirically evaluate any development.

The study was carried out within Initial Technology Teacher Education (ITTE) and involved over 270 undergraduate students. A number of preliminary studies were carried out to address deficiencies identified in the literature relating to freehand sketching. Using a pre and post test design, the study applied a model of sketching activities which ranged along a continuum from observation to imagination. The effectiveness of the model was examined using various methods (such as visual and verbal protocols (Middleton, 2008)) which captured the tacit and implicit nature of sketching behaviour and cognition.

The application of Comparative Pairs (Kimbell, 2008) as an assessment tool for pre and post-instruction conceptual sketches provided a novel method of measuring improvement. It was found that students sketching ability significantly improved as a result of completing the model of activities. The magnitude of improvement was dependent on a number of factors including motivation and previous learning experiences. The model of activities was effective in promoting the ability to use sketching as a communication and problem solving tool. It was found that the model of activities could be delivered by independent teachers. A number of findings relating to students sketching behaviour and cognition were correlated with literature associated with sketching expertise.

The study concludes that freehand sketching skill can be developed through appropriate instruction. An empirically tested model of instruction which promotes sketching ability was designed and validated. This has significant implications for the development of pedagogies within Design and Communication Graphics (DCG) and other technology subjects.
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1 INTRODUCTION
1.1 Background

In response to a rapidly changing global society which promotes the development of technological capabilities, the Irish government has been particularly proactive in addressing the area of technology education. Refined curricula in technology education throughout the world incorporate a creative design element that is becoming increasingly recognised for developing intellectual skills (Kimbell, 1986) and technological capabilities (D.E.S., 2007a).

A complete overhaul of technology based subjects studied at Senior Cycle (pupils ranging in age from 16-19 years) in Irish second level1 schools, has resulted in the drafting of four new subjects with two of these; “Design and Communication Graphics” (D.E.S., 2007a) and “Technology” (D.E.S., 2007b) having been implemented in September 2007.

The rationale behind the implementation of these new subjects was to create a fundamental shift in focus from a purely traditional craft based approach to a more creative design based philosophy that still embraces and values the craft based emphasis. The change in focus of the subject area, particularly towards communication and design promotes the utilisation of freehand sketching as a supporting medium for ideation, problem solving and flexible visualisation within design driven tasks as well as tasks involving plane and descriptive geometry.

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1 Second level education in Ireland is the equivalent of high school education where pupils generally range in age from 12-18 years old.
1.1.1 Design and Communication Graphics (DCG)

“Technical Drawing” which was the predecessor to “Design and Communication Graphics” (DCG) until 2007, focused on mechanical drawing, such as traditionally used by draftsmen to create schematic drawings using pencil and drawing instruments. It was assessed using a terminal drawing examination only.

The new subject, Design and Communication Graphics (DCG) consists of three main elements:

- Plane and Descriptive Geometry (similar content to Technical Drawing)
- Communication of Design and Computer Graphics
- Applied Graphics

The subject is assessed based on two components:

1. A terminal examination which aims to assess students understanding and ability to apply principles from both plane and descriptive geometry and the applied graphics area of the syllabus.

2. A course assignment which involves the completion of a design investigation and a modification or concept design that utilises appropriate modes of communication including freehand sketching, CAD and other ICT.

The development of cognitive and psychomotor skills for graphical communication, problem solving and critical thinking are primary aims of technological subjects in the Irish second level system. The ability to freehand sketch was not considered as a fundamental skill in the previous “Technical Drawing” subject but it is now considered as an important tool in “Design and Communication Graphics” (DCG), and this promotes various challenges. During their study of DCG, students are challenged by defined
problems in plane and descriptive geometry as well as ill-defined everyday problems in design tasks. Of particular interest to the current study is to develop the student’s ability to utilise freehand sketching as a medium for exploring a wide range of graphical problems.

The objective for including freehand sketching in DCG is to promote creative thinking, discovery and personal decision making (D.E.S., 2007a). The development of these skills has both cognitive and psychomotor benefits, but there are also broader educational benefits. Freehand sketching can act as a support for the “visualising instinct” (Fish, 2004) in addition to promoting the “synthesising mind” (Pink, 2006, Gardner, 2006).

The implementation of Design and Communication Graphics (DCG) has resulted in teachers requiring professional development courses in order to develop their sketching skills and utilise these as a tool for ideation, problem solving and flexible visualisation. This professional development of teachers and its impact on student performance in state examinations are described in the next section.

1.1.2 Developing Teachers Sketching Skills

“He’s a good sketcher… he can draw anything…” (Yang, 2007). The debate surrounding sketching ability and whether it is learned or innate has influenced various research studies within disciplines such as primary education (Hope, 2008), engineering design (Yang, 2007) and art education (Edwards, 1989).

In order to prepare and support teachers to implement the suite of new subjects, a fulltime subject support service known as t4 was established under the auspices of the Teacher Education Section of the Department of
Education and Science. Commendable work was carried out by $t^4$ in providing teachers of DCG with the opportunity to develop their sketching skills as well as making various classroom resources available. During in-service training, teachers were encouraged to explore a range of sketching media and techniques used by industrial designers including “crating” and “primitives” methods (Storer, 2008), which involved the generation of both sketches and annotations. An example of the type of activities which was explored is illustrated in Figure 1.

![Figure 1 - Examples of sketching type activities used to train practicing teachers](image)

Based on the work carried out by $t^4$, there was evidence to suggest that further exploration and development of teachers’ skills was required. A concentrated effort in developing these skills further, would contribute towards meeting the potential of sketching as a support tool for visual thinking in technology subjects.
An analysis of recent chief examiners reports (S.E.C., 2009a, 2009b), work carried out by the national subject support service and related literature reveals the following:

- Subsequent to the inaugural examination of design based tasks in 2009, the Chief State Examiner reported that freehand sketching required further emphasis, development, and promotion within schools. Pupils appeared to have significant difficulty sketching design solutions and ideas with a considerable number resorting to using measuring equipment and tracing methods (S.E.C., 2009b).

- The activities which practicing teachers engaged in during the stages of professional development revealed a dependence on observational drawing of representations depicting inanimate objects (such as shown in Figure 1). Sole reliance on this type of activity mirrors Arnheim’s (1978) “copycat mentality”, inducing inhibition, dependence and false security.

There was insufficient evidence within the training provided by t4 to suggest that freehand sketching was promoted as a conceptual tool for ideation and problem solving. This is also supported in a wider context in areas such as design education and the study of the role of sketching in visual mental imagery where the cognitive procedures and behaviour of expert sketchers are defined. Some characteristics of expert sketchers (as defined within the literature) include the following:

- Expertise in sketching is associated with high levels of creativity (Verstijnen, 1998b).
- Expert sketchers tend to use sketching as a “sense-making tool” (Jonson, 2005).
- Expert sketchers tend to communicate significantly more detail in their sketches (Yang, 2007).
Based on these defined characteristics and the objectives of freehand sketching within DCG, it can be concluded that the ability to freehand sketch is a complex cognitive skill and it is much more tacit and implicit than the resultant external representations produced with paper and pencil. It is considered critical to develop and examine these cognitive skills if freehand sketching is to be fully embraced as a “sense making activity” (Jonson, 2005).

1.1.3 Examining expertise in sketching ability

Verstijnen et al. (1998b) argues that many of the techniques presented within the body of literature relating to the development of freehand sketching ability are novel but the effectiveness of these is largely subjective and anecdotal in nature and as a result it may be subject to debate. A valid scientific argument is therefore required to determine whether sketching is an innate or learned skill.

An example of a valid scientific measure that has been applied to examine sketching skill is visual and verbal protocol analysis. Research that applied this method to determine the cognitive procedures and behaviours during sketching based tasks was carried out by Suwa et al. (1998b), Kavakli et al. (1999) and Middleton (2008). All of the studies conducted by these researchers used specific schemes to determine differences in sketching behaviour and cognitive actions between novice and expert designers. However, relatively small numbers of students have been reported on and there were no significant studies that applied scientific measures such as visual and verbal protocols to determine the effectiveness of strategic instruction in developing sketching ability.

There are notable indicators to suggest that links exist between different bodies of research literature including; the role of freehand sketching across
disciplines such as art (Edwards, 1989), design (Goldschmidt & Smolkov, 2006), engineering (Yang, 2007), educational based psychology (Finke, 1990) and the application of methods to measure cognition and behaviour during sketching based tasks (Middleton, 2008). Through the exploration of all of these areas it was envisaged that a number of research questions could be investigated. These are presented in the next section.

1.2 Research Questions

The following exploratory research questions provided a basis for investigating several facets regarding the development of freehand sketching ability.

1. The ability to freehand sketch and whether it is innate or learned is the subject of many debates within literature concerning freehand sketching. Is it possible to teach students how to freehand sketch in a predictable and effective manner?

2. In developing the ability to freehand sketch it is important to consider the wide range of student abilities and their levels of motivation. In terms of developing a model of learning activities, what are the fundamental competencies that need to be developed in order to freehand sketch effectively?

3. Literature concerning the examination of freehand sketching ability is limited within technology education and it tends to be varied and based on subjective inspection within art and design education. How can a proposed model of learning activities that promotes the development of freehand sketching competencies be validated to highlight its effectiveness?
1.3 Plan of the research study

This research study endeavoured to explore if the ability to freehand sketch could be learned. In order to establish this, a model of strategic activities was designed, implemented and evaluated. The research was carried out with undergraduate students of Initial Technology Teacher Education (ITTE). There were a number of reasons for this and they include the following:

- A majority of the students did not previously receive any formal instruction in freehand sketching thus increasing the likelihood that there would be a significant number of novice sketchers in the group.
- The students had previously completed teaching practice at second level which gave them an insight into the complex and dynamic nature of second level teaching.
- A core element of the third year graphics module that the students studied at the University of Limerick was concerned with the development of freehand sketching ability and how it is used as a tool for exploring principles of plane and descriptive geometry as well as solving and communicating design problems.

1.4 Aims and Objectives

1.4.1 Aim of research

The aim of the research was to explore how core competencies in freehand sketching could be developed through a novel and original model of activities and to examine the effectiveness of these using appropriate methods.
1.4.2 Objectives

1. To determine whether the ability to freehand sketch is learned or innate.

2. To design a model of activities that promote the development of core competencies associated with expertise in freehand sketching.

3. To examine the nature of the students learning experience while participating in the model of activities using appropriate qualitative and quantitative methods.

4. To measure the efficacy of the model in developing sketching ability through the application and triangulation of different methods at pre and post-instruction.

5. To explore relationships and trends in the research data in order to establish if improvement in the ability to freehand sketch has broader cognitive implications.
2 LITERATURE REVIEW
2.1 Introduction

Sketching is one of the oldest and most fundamental tools used by designers, engineers, artists and geometricians to explain as well as solve problems. It has been found that sketching experiences in design and technology education are problematic (Welch, 1999, S.E.C., 2009b) and that children generally are not introduced to the fundamentals of freehand sketching which can help them to develop cognitive and affective attributes to succeed in design tasks (Newcomb, 2007). The aim of the current research was to establish and develop these fundamentals through a model of sketching activities, the effects of which were examined using various methods. This chapter highlights the underlying research issues influencing the current study through a review and analysis of pertinent literature across a number of interrelated areas which include the following.

- **A Context for Freehand Sketching**: Various definitions for freehand sketching, its application across multiple disciplines and its broad values are considered.

- **An Exploration of the Cognitive Architecture**: The complex cognitive issues that often tend to be overlooked when designing appropriate models of instruction are reviewed. Particular focus centres on central systems of the cognitive architecture such as thinking, human memory and learning.

- **Measuring and Defining Expertise in Freehand Sketching**: The characteristics of expert sketchers are considered in addition to the methods commonly applied to examine this expertise.
2.2 A Context for Freehand Sketching

There are ambiguities within the literature surrounding the purposeful mark making on a surface using a medium such as pencil. Some researchers refer to this process as “sketching” while others refer to it as “drawing”. Fish (1990) presents an interesting distinction between the two terms. During the “sketching” process modification of information always occurs by mental manipulation. Purely objective “drawing” that does not involve mental manipulation of imagery, does not count as sketching. The research presented within this chapter considers “drawing” and “sketching” along a continuum that ranges from observation to imagination (Fish, 1990).

Goldschmidt (2003) describes two essential components of “drawing”. Firstly, it is important that drawing is a fluid activity, which does not give spare attention to the production process. The second component (which is optional) concerns the command of orthogonal projection, which enables the precise communication of an object based on geometric rules. On the other hand, “sketching” is a “systematic dialectic” between seeing and imagining (Goldschmidt, 1991). Fish (1990) considers sketching as a support tool for the synthesis of visual mental imagery. The demand for sketching is stimulated by the need to foresee the results of manipulation and synthesis of objects without actually seeing or executing such operations. Fish (1990) also considers sketching as a support for the visualising instinct.

A core element of this chapter reviews the literature surrounding freehand sketching across different disciplines. “Drawing” within the “seeing” element of the continuum is considered as a fundamental stepping stone in developing the necessary skills to freehand sketch. Its role within art education is described in the next section.
2.2.1 Drawing in Art Education

The copying paradigm has been the subject of considerable debate among art educationalists for a number of years. Copying of drawings and paintings has been accused of being restrictive in addition to promoting dependency and false security (Lowenfield, 1975) while inducing a copycat culture that is detrimental to the development of the human mind (Arnheim, 1978).

In contrast to these views, Wilson and Wilson (1977) support the conventional position for drawing where it is claimed that copying is children’s preferred drawing strategy as drawing is a “conventional sign system”. Acquiring knowledge of the sign system is imperative as the perceptions that people use everyday are too numerous and complex and cannot be readily converted into graphical images. The initial steps (adopted by many within art education) in acquiring this sign system through observational type drawing are achieved through a model of drawing activities designed by Edwards (1989).

2.2.1.1 Drawing on the Right Side of the Brain (Betty Edwards)

Perceived as one of the leading players in teaching freehand drawing, Edwards (1989) has been acclaimed by many (Cocks, 1990, Pink, 2006). Edward’s hypothesises that drawing is a whole skill that requires only a limited set of components. The components of drawing that Edward’s describes are as follows:

- The perception of edges
- The perception of spaces
- The perception of relationships
- The perception of lights and shadows
- The perception of the whole, or the gestalt (Edwards, 1989)
Based on the above components, Edward’s devised a strategy that incorporated specific activities that should be completed successively over a thirty hour period. The strategy involves exercises such as:

- **Upside Down Drawing**: This is where a person copies an inverted composition at a full size scale by analysing and communicating regular and irregular geometries.

- **Negative Space Drawing**: This involves the composition of a chair based on the negative or empty spaces surrounding the chair. Sophisticated sighting and measuring tools are also used.

The illustration in Figure 2 shows an example of the pre and post-instruction drawings after a five day intensive training course with Edwards. The model of instruction is very beneficial in developing the ability to objectively draw and it is considered as a prerequisite in progressing along the “seeing” to “imagination” continuum as described by Goldschmidt (1991) and building a “conventional sign system” (Wilson & Wilson, 1977). However it could be considered by some as one dimensional with a sole purpose for artistic expression as the strategy is only focused on objective drawing. A comprehensive insight into role of “drawing” within primary education is presented in the next section.

![Figure 2 – Initial development of author](image)
2.2.2 Drawing in Primary Education

Hope (2005, 2008) provides an insight into her observations of children’s drawings during design based activities. She describes a metaphor (Figure 3) for drawing where it is considered as a “static container” for design ideas that are taken on a conceptual “journey” across a surface (Hope, 2008). The external representation of existing ideas on a surface creates a building block or container that can be brought on a conceptual journey where the interaction of images and ideas aid in the development of new constructs.

![Figure 3 – Hope’s dual metaphor of drawing (Hope, 2005, p.46)](image)

Hope (2008) provides an informed breakdown of children’s drawings into six dimensions, including; Drawing to Play, Mean, Feel, See, Know and Design.

**Drawing to play**

This dimension explores the relationship between play and creativity. The importance of engaging in discovery learning with a range of media before and during the process of producing something creative is essential. Playing with ideas and bringing them on a conceptual journey is only possible when there is an understanding and appreciation of the materials and techniques used to express them (Hope, 2005, 2008).

**Drawing to mean**

The initial purposeful marks that make a drawing stand as a visual analogy for ideas in the imagination and how people perceive the world around them. The combination of drawing and annotations provide an intermediate for recording symbolic understanding. Drawing is a critical link between the
analogies created by the imagination and the external world of communication and expression of ideas (Hope, 2008).

**Drawing to feel**
The role of drawing as an activity of creative endeavour develops a sense of fulfilment, well being and even a sense of spirituality in people (Hope, 2008). The act of creating a sketch and engaging in deep levels of planning and empathy over a period of time can have a significant effect on a child’s well being as this engages the frontal lobes of the brain that also controls emotion (Ranganath, 2006).

**Drawing to see**
There are an infinite number of correct ways to represent the world. Drawing to see what is observed is no longer a means of copying but a detailed analysis of “seeing as” and the representation of varying styles and symbolic manipulation of what is inside the “container” during a conceptual “journey” (Hope, 2008).

**Drawing to know**
This dimension concerns the use of drawing as a means of problem solving in areas such as mathematics and geometry. Even though line drawings (which are outline drawings with no rendering) may be considered drawing in its simplest form, they can still be used effectively for modelling concepts and complex abstract ideas. The utilisation of line drawings through conceptual mapping enables classification and synthesis of solutions.

**Drawing to design**
This is the final dimension and it is where the previous five dimensions are synthesised to represent, generate and develop creative ideas. It is the pinnacle of drawing as it requires an in-depth understanding of how
drawing as a “container” can be used to represent a conceptual “journey”. Drawing becomes an essential tool in the personal creation of a story that began with “Drawing to play” and culminates in “Drawing to design”. Providing students with an opportunity to design and invent using their own knowledge and understanding has a critical role to play in technology education as well as a wider range of disciplines.

In terms of the observation to imagination continuum described by Fish (1990), the dimensions for drawing observed by Hope (2008) provides an indication of a natural progression away from “drawing to see” or drawing from “observation”. Drawing to play, mean, feel, know and design could be considered more closely aligned with a journey towards the “imagination” phase of Fish’s (1990) continuum and therefore as “sketching”. The role of sketching within design education is described in the next section.

2.2.3 Sketching in Design Education

Within design education, sketching is widely considered as a medium for recording the journey through iterations and communicating solutions to problems (Schutze, 2003, Storer, 2008, Hope, 2008). Storer (2008) considers the importance of industrial designers becoming experts in sketching despite the emergence of sophisticated CAD software. Various sketching techniques such as crating and primitives (Figure 4) that are utilised by industrial designers are presented by Storer (2008) and the importance of building a “graphical library” of products and images that can be accessed during design activities is also considered.
McKim (1980) describes a “collective graphic memory”, which is central to his model of visual thinking where seeing, imagining and drawing are synthesised (Figure 5). This memory provides an immediately accessible database for the stimulation of design ideas and is comparable to the Storer’s (2008) “graphical library”. A technique for accessing and building on these “graphical libraries” is described in the next section.

2.2.3.1 Brainsketching

Van Der Lugt (2002) describes the importance of designers being able to use freehand sketching for generating and communicating ideas. He presents a novel idea generation technique known as “Brainsketching” which is a modification of the “brainwriting technique” (Geschka et al., 1973). Brainsketching involves group members presenting their ideas for a specific design brief on a large sheet of paper. After a few minutes the group members swap sheets and explain their ideas to each other. Typically five
rounds of sketching take place and building on other peoples ideas is emphasised.

Brainsketching has several merits including; participants are involved in a group idea generation technique while at the same time they are afforded the opportunity to independently express and communicate ideas. Van Der Lugt conducted an experiment with 20 participants to establish the differences between brainsketching and brainstorming as idea generation processes. It was found that during brainsketching, designers produce ideas that have significantly more connections with earlier ideas while during brainstorming participants produced significantly more ideas. While both idea generation techniques have their merits, the novelty of brainsketching and its potential for application within the current research study is of particular interest.

Building on the role of freehand sketching within different disciplines, it is important to consider its broad values in order to gain a deeper understanding beyond the resultant external representations. These are presented in the next section

2.2.4 Value of Freehand Sketching

Fundamental to creative expression and designing, sketching offers a medium to problem solve, record ideas for later use and to explore design modifications and alternatives (Prats, 2009). It is a low cost, fast and flexible tool (Prats, 2009) that allows people such as designers, problem solvers and geometricians to generate external representations or early sketches that can be utilised as a medium in reflexive conversation between the sketcher and the brief (Kim, 2009) as a “sense making activity” (Kimbell, 2004, p.137).
Sketching is the ability to produce a snapshot image of cognitive activities (Schutze, 2003) during the development of visual, creative ideas and hypotheses (Fish, 1990, Suwa, 1998a). Initial sketches or “study sketches” are completed in the early stages of design activities and are of particular interest in technology education. Freehand sketching in DCG promotes innovation and creativity in design based activities as well as tasks which require geometric problems to be solved. These result in sketches being generated which are sometimes so idiosyncratic that they are only comprehensible by their maker (Goldschmidt, 1991).

The demand for sketching is stimulated by the need to foresee the results of manipulation and synthesis of objects without actually seeing or executing such operations (Fish, 1990). The utilisation of scaffolds such as words, pictures and models as imitations of objects, scenes or events not physically present, significantly increases the ability to engage in mental visualisation (Fish, 1990).

2.2.4.1 Descriptive and Depictive Representations

The representation of synthesised and manipulated ideas in the mind’s eye gives rise to the need to externally communicate that information. Analysis of Palmer’s “ordered triple” that consists of a represented world, a representing world and an interpretative process that maps the first on to the second is central to theories in cognitive psychology (Palmer, 1978, Fish, 2004). Palmer identifies two fundamentally different systems of representation as descriptive and depictive.

Descriptive representations are propositionally based, amodal and have extrinsic meaning where language uses arbitrary sign systems to describe objects. In contrast, depictive representations are not dependent on a set of
rules, they are modal and they cause visual experiences that have intrinsic meaning (Fish, 1990). Although there appears to be a dichotomy between the two theoretical forms of representation, it is more suitable to view both as a continuum.

2.2.4.2 External Representations

External representations such as sketches can be used as a catalyst to shift from purely descriptive representations to more depictive representations. They facilitate inference, problem solving and understanding through diagrams, sketches, charts, graphs and scribbles (Suwa, 2002). External representations are of benefit to working memory load as they provide an external library for information that must otherwise be stored in the mind. This in turn facilitates the ability to compute complex mental problems. Secondly, they facilitate discovery learning and reasoning that are both visuo-spatial and metaphorical, resulting in increased levels of perceptual judgement and calculation (Suwa, 2002). Thirdly, external representations encourage association among elements of conceptual knowledge and are a source of stimulation in solving problems and growing creative ideas (Goldschmidt, 1994, Suwa, 1997).

The externalisation of visual ideas and visual imagery facilitates its reorganisation, reconceptualisation and reformulation (Suwa, 1997). The construction of a set of concepts into external representations has a modelling effect which leads to new discoveries and hypotheses (Suwa, 1997). Externalisation of visual ideas has significance in design and technology education where creative design is regarded as the coordinated co-generation of concepts and perceptual findings through external representations such as sketches (Suwa, 2002).
As sketching is one of the fundamental modes of externally representing visual ideas, the special attributes of sketches provide an insight into underlying cognitive processes that predicate them. These are presented in the next section.

### 2.2.4.3 Special Attributes of Sketches

Sketching has experienced little change since Leonardo da Vinci (1452-1519). The uniqueness of hurried and untidy sketches incorporating rough hatching and linetypes using mediums such as crayon, pencil or watercolour on scrap pieces of paper remains unchanged. Examination of these unique attributes gives an insight into the underlying cognitive processes that occur during the production of external representations (Fish, 1990). The attributes of sketches can be outlined as follows:

- Sketches use two dimensional sign systems that include descriptive linetypes as well as written notes to represent three dimensional visual information (Deregowski, 1970, Fish, 1990).
- Linetypes and sign systems that are communicated in sketches are descriptive and depictive in nature and assist in the mental gymnastics between two modes of visual representation.
- Sketches contain both selective and disjointed information. They are records of a sequence of acts that combine visual perceptual information with images generated from memory (Fish, 1990).
- Sketches contain deliberate or accidental indeterminacies to help rouse the mind to creative thought processes and invention. Indeterminacies include scribbles, smudges, rough cross hatching, dark mysterious areas of shadow and shade as well as empty or negative space.
Following the review of pertinent literature so far in this section surrounding the application, value and special attributes of freehand sketches it is clear that there are underlying complex cognitive procedures that predicate the ability to freehand sketch effectively. As the capacity to perceive, memorise, think and learn is commonly misunderstood among teachers and educational specialists (OECD, 2002, Stillings, 1995), the next section provides an overview of the cognitive architecture with particular reference to central systems and visual mental imagery.

2.3 Exploring the Cognitive Architecture

As a result of both pressure to improve overall school performance and excitement and interest about educational based psychology, many myths and conceptions have grown outside the scientific community with regard to the mind and the brain (OECD, 2002). Both cerebral hemispheres of the brain have unique functions in determining the behaviour of people with the right hemisphere generally having non-verbal and spatial characteristics while the left hemisphere generally has verbal, logical and linear characteristics (Yellin, 1983).

The human mind is a remarkable information-processing system that is astonishingly powerful in most instances and yet surprisingly limited in others (Stillings, 1995). The lack of understanding and exploration of how the natural intelligence processes information is a common root problem in science and engineering disciplines that has led to the development of disciplines such as cognitive science, Artificial Intelligence (AI) and Cognitive Informatics (CI), (Wang, 2003). Cognitive psychology concerns human cognition. The capacity to perceive, memorise, think, learn and engage in problem solving is generally misunderstood among teachers and educational specialists (OECD, 2002, Stillings, 1995). Given the broad level
of abilities that teachers of technology subjects are faced with, it is important to have an understanding of human cognitive potential, its information processing capacities and mechanisms.

Humans receive information through their senses, engage in some form of thought about that information and carry out physical actions through voluntary muscular movement. Central to the human cognitive architecture (Figure 6) are; “sensory systems” including vision, hearing, taste/smell and touch, “central systems” concerning thinking, memory, learning and attention and “motor systems” which include physical and verbal responses (Stillings, 1995). For example, during observational drawing tasks students can use all three systems of the human cognitive architecture. They study the artefact by using their vision, they engage in some thought about the artefact by storing information in their short-term memory and, finally they communicate this visual mental image by physically manipulating a pencil to generate a drawing.

![Figure 6 - Global view of the cognitive architecture (Stillings, 1995)](image)

Literature surrounding the cognitive factors that influence the ability to freehand sketch is primarily concerned with the development of “graphical libraries” (Storer, 2008) and “conventional sign systems” (Wilson & Wilson,
1977) and the subsequent access and manipulation of these during sketching activities. The following section presents an overview of human memory systems and this then provides a basis for examining the importance of visual mental imagery.

2.3.1 Memory

The completion of complex cognitive tasks is based on the retrieval of large amounts of information from memory (Ericsson, 1995) or the ability of living organisms to acquire, retain and use information or knowledge (Tulving, 1987). One of the most interesting aspects of human cognition is the ability to remember facts and previous events when needed. Memory situations can be broken down into three discreet features: “acquisition” when the target knowledge is acquired (e.g. learning the how to say ones name in a foreign language), “retrieval” when the target knowledge is accessed for utilisation in some cognitive process and “retention interval” is the time between the acquisition and retrieval stages when knowledge is stored (Stillings, 1995).

Storage of acquired target information is carried out by construction of a “memory trace” (Tulving, 1991) in the cerebellum of the brain (Stillings, 1995, Krupa, 1993) through particular memory systems. Utilisation of different memory systems depends on the level of activation on acquisition and the retrieval period. Formation of new knowledge depends on the construction of controlled processes or encoding strategies that result in information being retrieved from short-term memory or transferred to long-term memory storage (Stillings, 1995).

2.3.1.1 Memory Systems

The classical theory of the cognitive architecture (Stillings, 1995) includes three types of memory: working memory (short-term), declarative and
procedural (both long term). Long term memory can be divided into three parts: Declarative Memory, Procedural Memory and a Perceptual Representation System (PRS) (vanGorp, 1999, Nilsson, 2003).

Declarative memory involves the recall of propositions and can be broken into two elements: “Semantic” memory and “Episodic” memory. “Semantic” memory is concerned with acquisition and retention of propositional information (e.g. memories of laws and organisational rules) while “episodic” memory refers to a hypothetical neurocognitive system (Tulving, 1991) based on temporal order of autobiographic and personal events (e.g. memories of funny or sad events in one’s life) (Ferbinteanu, 2006). Distinction between episodic and semantic memory is possible in terms of “implicit” and “explicit” memory. Implicit memory involves the expression of knowledge by a person without awareness of its acquisition and this is directly related to semantic memory (e.g. what is your date of birth?). In contrast, explicit memory can be associated with episodic memory and involves the expression of knowledge in relation to previous experiences (e.g. Where did you buy your first car?) (Tulving, 1991, Stillings, 1995).

“Procedural memory” (vanGorp, 1999, Stillings, 1995, Nilsson, 2003) involves the acquisition and utilisation of behavioural motor skills (e.g. walking, swimming, and biking) (Kraemer, 2000, Nilsson, 2003). The acquisition of procedural skills is gradual and slow but at the same time automatic and noncognitive. Loss of knowledge on how to carry out the procedural skills does not occur (in most cases) as a person can still perform a skill even though it may not have been practiced for many years (Nilsson, 2003).

The “perceptual representation system” (PRS) is used for identifying objects in the surrounding environment (Nilsson, 2003) as structural entities and facilitation of such perception is carried out through “priming” (Tulving,
Perceptual priming operates on physical perceptual appearance of objects and in contrast to semantic and conceptual priming it has little to do with meaning. Perceptual priming is evident when visual similarities between cues and a target are established. Examples include a face, a word, a picture or a line drawing of an object (Tulving, 1991). Evidence suggests that perceptual priming takes in the posterior area of the brain while the processing of meaning is associated with frontal areas (Stillings, 1995).

2.3.1.2 Short term memory

*Short term (working) memory* is a complex system that involves a range of interacting subcomponents that provide an interface between memory, attention and perception (Stillings, 1995, Baddeley, 1998). Integral to the model of working memory is a central executive and two subsystems (Figure 7), specifically, the “*phonological loop*” and the “*visuo-spatial sketchpad*” (Baddeley, 1998, Bruyer, 1998) that function independently of each other. The phonological loop consists of a “*phonological store*” and an “*articulatory recapitulatory system*” (e.g. these are utilised when a person learns new sounds or words). The visuo-spatial sketchpad stores visual non-verbal information in short term memory (e.g. the shape of an artefact which a person must memorise and then communicate shortly afterwards) (Bruyer, 1998, Baddeley, 1998).

Limitations of working memory have a significant effect on human cognition, constrains comprehension (Adam-Just, 1992) and determines how
complex cognitive tasks are solved (Stillings, 1995). Research has found that working memory can only store three or four pieces of information at any one time (Cowan, 2001, Broadbent, 1975) and this further highlights its limitations. Pedagogical solutions for at least partially overcoming the limitations of working memory include:

- Redesigning tasks to reduce working memory load
- Utilisation of an external memory such as writing and sketching on notepads
- Application of “chunking” where complex representations in long term memory function as a single representation in short term memory through coding and alternative meanings (Stillings, 1995)

2.3.2 Visual Mental Imagery

The study of the nature of visual image representation and the processes involved are the subject of debate in cognitive science and it is of notable importance in diverse areas such as design education, medical surgery (Brandt, 2006) and language studies (Bergena, 2007).

“Visual imagery” is a common term that is referred to within the cognitive focused literature. Visual (or mental imagery) is a unique, “top-down” (Borst, 2008) “graphics processor” like component of the cognitive architecture, which plays an integral role in processing visual information (Stillings, 1995). It can also be defined as “experience resembling perceptual or motor activity” influenced by “propositional schematic representations” that occurs when the relevant external perceptual stimuli or motor actions are absent (Bergena, 2007, Ranganath, 2006). In contrast, visual perception is a “bottom-up process” (Borst, 2008) that occurs while a physical stimulus is being viewed resulting in the creation of “modality specific internal representations” (Kosslyn, 1993).
2.3.2.1 Functions of Visual Imagery

The visual image is a picture in the “mind’s eye” created by the “computational resources” of the visual system, that preserves the shape and spatial arrangement of objects for utilisation at a later time in the future (Hollenberg, 1970, Stillings, 1995). In terms of early childhood learning visual imagery has a dual purpose. It can be hypothesised that imagery facilitates the initial stages of learning names of objects in the child’s environment in addition to generating visual imagery and propositions in long term memory (Hollenberg, 1970).

Visual imagery is also used in everyday tasks such as being able to plan a route for a walk or the arrangement of furniture in a room. This type of problem solving activity synthesises goal orientating thought that utilises both propositional schematic long-term memory in addition to visual imagery that contain the required spatial information (Stillings, 1995).

Limitations of the visual imagination are a combination of the limited capacities of central processing and visual attention. Image processing is initiated by goal oriented thought through the short term working memory. The limited capacity of short term working memory in retaining three or four chunks of information at any given time (Cowan, 2001, Broadbent, 1975) limits the quantity of goals and schemas that are providing the impetus for image formation and processing.

Two fundamental components of visual mental imagery are “mental scanning” and “mental rotation”. What shape are the ears of a cat? Which is a darker green, an avocado or a pea? For both of these questions a person will find that they acquire images from long term memory and engage in visualisation. However, if a person was asked how many windows are in their living room, many will report visualising the image and engaging in a
“systematic shift” in attention (Denis, 1999, Borst, 2006) over the walls and windows in the room. This constitutes “mental scanning” (Denis, 1999, Stillings, 1995).

Mental rotation is the ability to operate on “visual mental images” in space (Wexlera, 1998) and this mental activity is analogous to the physical manipulation of actual objects (Kosslyn, 1998). For example; the ability to rotate a tetrahedron in the minds eye so that its base is at 70° to the horizontal plane and one edge of the base is parallel with the vertical plane. Research has shown that internal motor imagery (Kosslyn, 1998) or visuomotor (Wexler, 1998) anticipation may be important in carrying out complex cognitive activities such as mental rotation.

2.3.2.2 Converging Evidence concerning Visual Imagery

It is difficult to determine whether particular processes or representations are biologically built in to the cognitive architecture (Stillings, 1995) and whether the same processes are used in visual imagery as visual perception (Farah, 1988). Physiological tests on brain damaged subjects have found that people with right parietal lobe damage have difficulty in processing mental rotations. This is consistent with the hypothesis that the right hemisphere of the brain specialises in spatial relations (Yellin, 1983). However, it has been found that people with left hemisphere damage have difficulty in mental rotations (Stillings, 1995). This reinforces the hypothesis that mental rotation involves the use of computational capacities in the left hemisphere to construct abstract descriptions of objects (Kosslyn, 1992).

In summary, visual imagery is critical to visual functions in terms of:

- Comparing distances among objects not physically present
- Comparing angles between and orientation of objects when viewed from different vantage points
- Verifying that a new object lies along a particular direction in relation to previously observed objects
- Developing the skill of mentally anticipating the consequences of visual movement (Finke, 1986)

In terms of developing suitable models of instruction, it is important for teachers not only to have knowledge of how the human mind works but it is also critical to understand how people acquire different skills. The next section presents literature that addresses this.

### 2.3.3 The Acquisition of Skill

#### 2.3.3.1 Automatic and Controlled Processing

A mixture of automatic and controlled processing, both of which use distinctly different regions of the brain (Satpute, 2006), is required for complex cognitive, perceptual and motor skills (Stillings, 1995). “Automatic processing” corresponds to a “reflexive system” (Satpute, 2006) that reduces demands as a result of practice. An example of automatic processing is where an experienced driver can pay attention to a radio station while driving and suddenly realise that they have driven for miles without paying attention to the driving task. “Automatic processing” facilitates the performance of another task concurrently and it is difficult to control the occurrence of the process (Stillings, 1995).

“Controlled processing” corresponds to a “reflective system” (Satpute, 2006) that requires the use of the limited capacity of working memory and attention (Stillings, 1995). In contrast to automatic processing, an inexperienced driver would require a great deal of attention when driving and would find
it very difficult to simultaneously listen to a radio. “Controlled processing” is goal oriented and flexible. It relies on fundamental built-in processes and the ability to utilise schemas stored in long term memory (Stillings, 1995).

Research that has been carried out on social cognition utilises two main testing methods to determine whether interest in a task is automatic or controlled (Satpute, 2006). The two methods are “subliminal presentation” and “cognitive load”. “Subliminal presentation” utilises a stimulus outside the awareness of a subject and if a process occurs unconsciously the interest is deemed automatic (Bargh, 1999). Secondly, “cognitive load” has been used to differentiate between the automatic and controlled processes of attribution where a resource-demanding task (controlled process) is performed concurrently with a task of interest (automatic process) (Trope, 1999).

In order to further comprehend the development of both controlled and automatic processing, the next section considers the stages of skill acquisition.

2.3.3.2 Stages of Skill Learning

It takes one hundred hours of learning and practice to acquire any significant cognitive skill (Fitts, 1964) to a widely acknowledged standard in demanding, complex activities such as chess (Chase, 1973) and musical composition (Hayes, 1981). Significantly, research has generally found that characteristics once attributed to innate talent are in fact the result of intense deliberate practice over an extended period of at least ten years (Ericsson, 1993).

Theorists have divided the process of skill learning into stages that represent the slow transition from control dominant processes to automatic dominant
processes. Different studies (Fitts, 1964, Anderson, 1983) have given these distinct stages different terms but in general all of their conclusions are similar.

Anderson (1982) considered that the process of skill acquisition falls into three stages. They are the “declarative stage”, “knowledge compilation” and the “procedural stage”. Firstly, the “declarative stage” occurs when the subject receives instruction and information about a skill (e.g. learning the different parts of a car… clutch pedal, gearstick etc.). The instructions are encoded as a set of propositions and stored as declarative knowledge. Behaviour during the declarative stage is error prone with periods of hesitation and verbalisation (Stillings, 1995).

The second stage of skill acquisition has been called the “knowledge compilation” stage by Anderson (1982). During this stage, parts of the new skill is “chunked” into a procedure that is fundamental to its performance (e.g. how the clutch pedal of a car is related to the gear stick) (Anderson, 1982, Stillings, 1995). A decrease in reliance on working memory is evident due to the fact that information does not need to be held in declarative form anymore. It also becomes increasingly noticeable that subjects find it more difficult to verbalise the process as in the procedural stage (Stillings, 1995).

The final stage of skill acquisition is the “procedural stage” where knowledge is “strengthened” and “tuned” (Stillings, 1995) in addition to a gradual speed up in the skill process (e.g. the ability to change gears smoothly becomes a natural reaction) (Anderson, 1982). During this stage it becomes evident that procedures are “maximally automatic” (Stillings, 1995) in addition to a “restructuring” and “shrinkage” of the demand for resources. Tuning results in procedures being controlled by an optimum range of inputs. This is in contrast to the previous two stages where a procedure may be sparked by an
irrelevant stimulus or could fail when the appropriate inputs are fired (Stillings, 1995).

2.3.3.3 Summary

The literature review has so far provided a context for freehand sketching followed by an analysis of the cognitive processes that predicate the ability to freehand sketch. The final section of the chapter considers research that defines expertise in freehand sketching in addition to various methods used to measure this expertise.

2.4 Measuring and Defining Expertise in Freehand Sketching

Literature concerning the measurement of sketching ability within technology education is very limited. In disciplines such as art and design education it tends to be varied and mainly introspective. The subjective assessment of ability rather than cognitive based assessment results in evidence being anecdotal in nature and subject to debate (Verstijnen, 1998b). In order to justify the underlying importance of freehand sketching, a valid scientific argument is required. Examples of methods used to measure and define sketching ability are presented in this section. The first of these involves criterion based assessment which was applied by both Yang (2007) and Goldschmidt and Smolkov (2006).

2.4.1 Criterion-Referenced Assessment of Sketching

Criterion-referenced assessment measures the performance of a student in relation to a pre-defined given set of criteria or outcomes Cohen et al. (2007). This type of assessment is commonly used to measure sketching
A summary of two studies are described in this section the first of which was conducted by Yang (2007).

2.4.1.1 Sketching skill

“Is sketching an innate, universal skill or can it be enhanced by strategic instruction?” (Yang, 2007). Yang (2007), presents the findings of a research project that explored the role of sketching skill in engineering design. The influence of instruction on sketching skill was assessed for a group of undergraduate designers who undertook a four week sketching course with particular emphasis on “sketch fluency” (Yang, 2007, p.477). The sketching tasks that were developed and applied included:

- “Mechanical Recall” – a bicycle was sketched from memory and the recall and visualisation of mental images was assessed.
- “Drawing Facility” – an organic object was sketched from a live composition and was assessed based on the ability to create clear, realistic, well composed drawings.
- “Novel Visualisation” – A three dimensional object was sketched based on a verbal description.

A selection of representative drawings for the three tasks are illustrated in Figure 8 with level 1 indicating the lowest drawing ability and level 3 indicating a higher ability.
Yang’s (2007) implementation of an assessment strategy is of particular interest. Aspects and features of sketches that are often taken into account include realism, drawing style and level of detail. Yang selected three independent sketching judges from a professional background in product design and engineering. A clear scoring criterion for each activity was devised and each sketch was codified into one of five levels of performance according to that criterion. An example of the criteria (based on mechanical design) that the assessors used for the mechanical recall task is shown below:

- Does this look like a bicycle?
- Are the essential components such as the frame, wheels, chain, and handle-bars shown?
- Are these connected in a way such that the bike would work mechanically? (Yang, 2007, p.477)

Yang (2007) hypothesised that by providing students with sketch instruction it would lead them to become more proficient at the skill which would
enable them to become more effective sketchers and engineers. Interestingly, it was found that students who received sketch instruction completed more sketches for their design tasks but with no significant change in their grades.

Following the description of the application of criterion-referenced assessment by Yang (2007) within Engineering Design, a similar study by Goldschmidt and Smolkov (2006) is presented in the next section.

2.4.1.2 Visual stimuli and their affect on sketching performance

Goldschmidt and Smolkov (2006) provide an insight into the role of external and internal representations in the visual thinking of designers. They present an interesting experiment that investigated whether visual thinking is predicated by the inner representations which use imagery alone or whether external representations have an affect on design thinking and sketching performance.

The experiment carried out by Goldschmidt and Smolkov (2006) involved 36 architecture and industrial design students. The purpose of the experiment was to establish the role of sketching and visual displays in design problem solving. Each student was required to solve two design problems through freehand sketching. Twenty-five minutes was given to solve each problem. The students were divided into three groups. Half of the students were required to sketch while they were designing and the other half were required to solve the problem in their head and were only allowed to sketch the solution to the problem at the end of the task.
Group 1 worked with no visual stimuli in the environment, Group 2 worked with a wide range of rich visual stimuli in the environment and Group 3 worked with a modest number of stimuli. These are illustrated in Figure 9.

![Research environments described by Goldschmidt and Smolkov](image)

Each sketching design solution was assessed for originality, practicality and general quality. The scores were given on a five point scale where 1 = low and 5 = high. Creativity was determined as a product of practicality and originality scores.

It was found that when designers were given ill-structured design problems at a conceptual level and in a short period of time that the presence of visual stimuli had an effect on the quality of sketched solutions. It was also found that creative and innovative thinking was sensitive to environments that provided potential cues and visual stimuli that promoted high-level design solution.

Following the above description of a study that was influenced by the role of visual mental imagery and visual stimuli, experiments in visual mental imagery that incorporate freehand sketching are described in the next section.
2.4.2 Experiments in Visual Mental Imagery

The externalisation of student’s visual ideas is made possible through various media such as Computer Aided Design, measured board drawings, rapid prototyping technology, presentation sketches and physical modelling. However, during the early phases of design, students can experience periods of anxiety and frustration in forming design ideas. Many designers tend to overcome this frustration by using “idea-sketches” which aid in the interaction with mental imagery for creative discovery.

The reason why artists and designers require externalisation for creative discovery is the subject of debate in research surrounding cognitive psychology. Finke (1990, 1988) reports that visual discoveries in imagery can be reliably induced in every person under appropriate laboratory conditions. In contrast to this, Reed and Johnsen (1975) report that the extraction of novel components is difficult through mental imagery alone and is significantly enhanced through sketching.

Reconciling these opposing conclusions surrounding mental imagery and creative discovery, Verstijnen et al. (1998b, 1998a) proposed two forms of processing within mental imagery which are combining and restructuring. “Combining” involves the joining of known components to form a novel whole whereas “restructuring” involves the decomposition of a component into incidental parts, not previously known to exist within the combination (Verstijnen, 1998a). These two measurable processes impose different cognitive challenges.

An example of the difference between “combining” and “restructuring” can be seen when the configuration on the left of Figure 10 is imagined. Reed and Johnsen (1975) proved that people will tend to form a mental image
consisting of two isometric triangles as shown in A, while the decomposition of the image into other novel components as in B, C and D is very difficult to perform using imagery alone.

Figure 10 - Example of the type of task used by Reed and Johnsen

Building on the research of Reed and Johnsen (1975) and Finke (1988), Verstijnen et al. (1998b) utilised a “Component Detection Task” and a “Figural Combination Task” to establish the nature of combining and restructuring tasks and the effect of paper-and-pencil support. The administration of the tests was varied by controlling groups (of both novice and expert sketchers), with some being compelled to sketch and others being denied the opportunity. In addition to this, they monitored spontaneous sketching activity and varied the number of novel parts in each configuration.

The results of the experiments concluded that externalisation through sketching has a significant positive effect on the ability to detect novel components in figural combinations through “restructuring”. Interestingly, it was also found that being compelled to sketch can have no additional value in “combining” tasks and that it can even deteriorate performance.
Expertise in sketching and the associated ability to engage in restructuring was also correlated with high levels of creativity. There was only one major difference between novel and expert sketchers. Novice sketchers performed significantly worse in restructuring novel parts in the administered tests. This provides a valid argument that “restructuring” is a fundamental component of sketching expertise.

As psychometric tests are widely used in educational research to provide an insight into cognitive characteristics and aptitudes, the next section presents an overview of some of these measures.

### 2.4.3 Psychometric Testing

Within the literature there is limited information on the relationship between clearly defined cognitive factors and performance in sketching based activities relating to visual imagery (Burton & Fogarty, 2003).

Psychometric tests such as the Differential Aptitude Tests (E.R.C., 2007) and the Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976) are battery tests designed for use in educational research and vocational guidance. They provide specialists with an insight into intellectual characteristics and aptitudes. Battery tests provide an insight into a range of abilities and these are more beneficial than tests that give a single score.

The Differential Aptitude Test, Form T (E.R.C., 2007) is a battery of tests designed for use in Irish schools and takes 3.5 hours to complete. There are eight subtests within the battery including:

- Verbal Reasoning
- Numerical Reasoning
- Abstract Reasoning
• Space Relations
• Mechanical Reasoning
• Clerical speed and accuracy, spelling and language usage

The Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976) was designed to identify certain aptitude factors in factor analysis studies (Elkstrom, 1979). The test is widely used in international based research and consists of 72 tests which are supposed markers of 23 latent cognitive constructs. The tests cover a wide range of abilities ranging from spatial, numeric, creativity and reasoning (Babock, 1997). Cognitive factors measured by the kit are listed in Table 1.

<table>
<thead>
<tr>
<th>Fluency Constructs</th>
<th>Spatial Visualisation Constructs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associational Fluency (FA)</td>
<td>Spatial Orientation (S)</td>
</tr>
<tr>
<td>Expressional Fluency (FE)</td>
<td>Spatial Scanning (SS)</td>
</tr>
<tr>
<td>Figural Fluency (FF)</td>
<td>Visualisation (VZ)</td>
</tr>
<tr>
<td>Ideational Fluency (FI)</td>
<td></td>
</tr>
<tr>
<td>Word Fluency (FW)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reasoning Constructs</strong></td>
</tr>
<tr>
<td><strong>Closure Constructs</strong></td>
<td>Induction (I)</td>
</tr>
<tr>
<td>Flexibility of Closure (CF)</td>
<td>General Reasoning (RG)</td>
</tr>
<tr>
<td>Speed of Closure (CS)</td>
<td>Logical Reasoning (RL)</td>
</tr>
<tr>
<td>Verbal Closure (CV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Miscellaneous Constructs</strong></td>
</tr>
<tr>
<td><strong>Memory Constructs</strong></td>
<td>Integrative Processes (IP)</td>
</tr>
<tr>
<td>Associative Memory (MA)</td>
<td>Number (N)</td>
</tr>
<tr>
<td>Memory Span (MS)</td>
<td>Perceptual Speed (P)</td>
</tr>
<tr>
<td>Visual Memory (MV)</td>
<td>Verbal Comprehension (V)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flexibility Constructs</strong></td>
<td></td>
</tr>
<tr>
<td>Figural Flexibility (XF)</td>
<td></td>
</tr>
<tr>
<td>Flexibility of Use (XU)</td>
<td></td>
</tr>
</tbody>
</table>

The Kit of Factor Referenced Cognitive tests enable a greater range of cognitive factors to be measured. It is widely used, internationally recognised and easily available. Triangulating the findings of psychometric tests with alternative measures of student cognition provides a further
insight into the tacit nature of sketching skill development. One of these other measures is visual and verbal protocol analysis. This is described next in the next section.

2.4.4 Visual and Verbal Protocol Analysis

Visual and verbal protocol analysis provides a rich source of data in relation to how people deploy a range of cognitive procedures and behaviours during specific tasks (Middleton, 2008). Research methodologies that use visual and verbal protocol analysis during design based sketching activities have been described by the likes of Suwa et al. (1998b), Kavakli et al. (2001) and Middleton (2008).

2.4.4.1 Comparing the sketching behaviour of novice and expert designers

Kavakli et al. (1999) present findings on their application of a protocol scheme by Suwa et al. (1998b) in an attempt to differentiate between the construction and interaction with sketches of novice and expert designers during the early stages of the design process. Two subjects were used in the study; one expert architect with 25 years of experience and one second year architecture student. Due to the very small sample size the results are only indicative but provide useful directions for other research. Kavakli et al. (1999) codified the visual and verbal protocols into Physical, Perceptual, Functional and Conceptual cognitive actions as in Suwa et al. (1998b).

In summary Kavakli et al. (1999) found that experts and novices differed in the following ways:

- The protocols for the expert contained three times as many segments and almost 2.8 times as many cognitive actions. A single segment is based on the smallest unit of meaning that suggest one cognitive
action. Cues for segmenting protocols include pauses, change of tone or conclusion of sentences.

- The expert produced significantly more pages of sketches and design alternatives than the novice.
- There was greater expression and detail in the sketches of the designer compared with the novice.
- The expert tended to modify existing depictions by revising and manipulating them while the novice sketched new depictions.
- The expert revisited old spatial organisational relations while the novice tended to discover implicit spaces.
- The expert was more focused on revisiting existing functions while the novice had a higher rate of implementation of a function.

Kavakli et al. (1999) concluded by highlighting the importance of further research into the behaviour of novice and expert designers during sketching activities in order to inform pedagogies that could enhance visual reasoning processes.

Even though the research presented by Kavakli et al. (1999) provides notable indicators surrounding the behaviour of novice and expert sketchers, the scheme is still considered too complex to delineate and requires further research. An overview of another protocol analysis scheme is presented in the next section.

2.4.4.2 Examining design thinking and freehand sketching

Middleton (2008) provides a detailed analysis of the application of visual and verbal protocol analysis to examine cognitive actions among design and architecture students during sketching based design tasks. Cognitive actions from the visual and verbal protocols were broken down into ten types of
procedures which were then assigned between three major categories which include; Exploration, Generation and Executive Control (Middleton, 2008, p.197).

A sample of the type of data that can be outputted using this scheme is shown in Figure 11 and Figure 12. Note the very different types of problem solving strategies applied. The expert engaged in significant exploration in the beginning and once problem solving commenced the problem was largely resolved by tentile 4.

![Middleton (2008) Competent Graph](image1.png)

Figure 11 – Plot showing cognitive procedures of a novice designer during a design based sketching task (Middleton, 2008)

![Middleton (2008) Expert Graph](image2.png)

Figure 12 – Plots showing cognitive procedures of an expert designer during a design based sketching task (Middleton, 2008)
Reliability is addressed by Middleton (2008) by providing a detailed description of the research setting, participants and the methodology applied. Considering the simplified breakdown of cognitive procedures and the detailed methodology described by Middleton (2008), it was felt that this research could provide a suitable model for examining the pre and post-instruction sketching behaviour of students in the current research study. A more detailed analysis of the research methodology applied by Middleton (2008) is described in the Methodology chapter.

2.4.5 Defining sketching expertise

Prior to progressing further, it is considered worthwhile to summarise the literature presented so far in relation to identifying the characteristics relating to expertise in freehand sketching. These include:

- Sketching expertise is comprised of two components. These are fluency and a command of the orthogonal projection system (Goldschmidt, 2003).
- Experts tend to use freehand sketching more effectively as a “sense-making tool” (Jonson, 2005).
- Expertise in freehand sketching is associated with high levels of creativity (Verstijnen, 1998b).
- Expert sketchers tend to perform better in “restructuring” tasks (Verstijnen, 1998b).
- Expertise in freehand sketching is associated with a higher number of cognitive actions during design based tasks (Kavakli et al., 1999).
- Expert sketchers tend to communicate significantly more detail in their sketches (Kavakli et al., 1999) (Yang, 2007).
- Evidence of association between spatial features and meaning within sketches tends to be higher in expert sketchers (Kavakli et al., 1999).
Experts tend to engage in significant exploration at the beginning of design based sketching tasks while the rate of generating actions tends to increase as the activity progresses (Middleton, 2008) (Figure 12).

It is important to realise that the definitions for expertise in freehand sketching are solely based on the findings of relevant studies in which scientific measures were applied. A number of the studies are limited in terms of the amount of participants and the findings are tentative however they do provide an informed basis for the design of this research.

2.5 Summary

A fundamental shift in focus of the Irish second level system towards developing students design driven aptitudes and technological capabilities has resulted in the need to develop teacher’s skills including the ability to freehand sketch. Although commendable work has been carried out by 

in an attempt to aid teacher’s development of freehand sketching ability, a number of concerns were highlighted within this chapter. One of the main concerns was how teacher’s skills can be further developed to reach a level of expertise that aligns with the literature.

Although there are ambiguities within the literature concerning what constitutes “drawing” and “sketching”, common themes emerge between different disciplines suggesting that there are overarching cognitive and behavioural benefits of being able to freehand sketch. The distinctions made between “drawing” and “sketching” are important to note. Fish (1990) considers sketching as an intermediate between observation and imagination while (Goldschmidt, 1991) considers two modes where drawing is considered as “seeing-as” and sketching as “seeing-that”. These distinctions
coupled with Edwards’ established approach for developing drawing ability provide a reference for designing the current study.

Unfortunately the literature is not coherent in terms validated models of instruction to develop competencies in freehand sketching. Part of the focus of the current research study was to address this problem and to develop a suitable model of learning activities. Devising this model of activities required an understanding of the cognitive architecture and in particular visual imagery and its role in acquiring the skill of freehand sketching.

In terms of examining the effectiveness of any model of strategic instruction it is necessary to apply suitable scientific methods. Numerous studies have applied scientific methods to measure the cognitive attributes, actions and behaviour of novice and expert sketchers. Limitations of these studies include the small number of research participants and there have been no significant studies carried out that examine the effectiveness of strategic instruction on the ability to freehand sketch within technology education.
3 PRELIMINARY STUDIES
3.1 Overview

In order to investigate the issues outlined in the Literature Review, a series of three Preliminary Studies were conducted. The findings of these studies then provided a basis for the design of a Primary Research Study (Figure 14).

The approach taken to carry out the research study within ITTE was as follows:

1. Preliminary Study 1 applied Edwards’ (1989) strategy with a small group of experienced second and third level educators of varying sketching ability to determine whether the ability to freehand draw was a teachable skill. The researcher provided instruction to the group of participants.

2. Preliminary Study 2 was carried out with a small group of novice undergraduate sketchers to gain a further insight into whether freehand drawing was a teachable skill and to determine the effectiveness of different activities which were designed as a result of
the findings of Preliminary Study 1. The researcher provided instruction to the group of participants.

3. Preliminary Study 3 was conducted with a large cohort of undergraduate students of ITTE to determine the efficacy of an applied model of drawing and sketching activities in developing the abilities of large class groups. A battery of psychometric tests was administered to determine any underlying cognitive attributes of expert sketchers. In order to establish if the ability to sketch was a transferrable teachable skill, a postgraduate student delivered the instruction to participants.

A description of the methodology and key findings for each of the Preliminary Studies are presented in the following sections.

Ethical approval was granted by the Faculty of Science and Engineering Research Ethics Committee at the University of Limerick prior to commencing the research study.

3.2 Preliminary Study 1

3.2.1 Overview

The objectives of Preliminary Study 1 were to establish the characteristics of perceived expert sketchers, evaluate the effectiveness of Edwards’ (1989) strategy for developing the ability to freehand draw and to determine whether the skill is innate or learned.
3.2.2 Methodology

The research was set out in two stages. The first stage aimed to establish the skill set and characteristics of people with an innate ability to sketch through an investigative focus group. Once these were determined, the second stage involved the design and implementation of an approach to explore the efficacy of Edwards (1989) strategy for developing freehand drawing skill. This was conducted using an applied test group.

3.2.2.1 Investigative Focus Group

Eighteen undergraduate students of technology education at the University of Limerick volunteered to participate in the focus group discussions. All of the participants classified themselves as having an innate ability to sketch.

Three sets of focus groups were formed with the intention of engaging the participants in discussions about their early sketching background, preferential learning styles, personal characteristics, influences and their personal approach to sketching. Each focus group session was recorded using a digital recording device and the results were collated.

The role of the researcher was only to stimulate and record discussions between the participants. Some typical questions which were asked included the following:

1. What are your sketching backgrounds?
2. Were you taught how to freehand sketch?
3. Describe your ability to freehand sketch.
4. How do you approach sketching tasks?
5. What environments do you typically prefer to sketch?
6. Do you evaluate your sketches? If so, how do you do this?
7. Are you still improving your ability to sketch?
When the focus group discussions were concluded, all of the audio files were examined and common characteristics were then identified.

3.2.2.2 Applied Test Group

The applied test group was composed of seven people. The following were the main descriptives for the group:

- All were qualified teachers of technology subjects.
- Five of the participants were undertaking post-graduate research at masters and doctorate level.
- Two participants were academics who lecture in the area of initial technology teacher education.
- The group was made up of six males and one female.
- The group was composed of two kinds of participant, those who claimed an average standard of sketching and a group who claimed they “cannot sketch”.
- All participants were right handed except for the sole female participant who was left handed.
- All participants were very interested in both developing their drawing skills as well as becoming reflective participants.

The applied test group completed a set of activities which were based on Edwards’ (1989) strategy over five evenings with each session lasting three hours. Questionnaires, critique exercises and group discussions were used throughout the course to evaluate both sketches and receive some participant feedback.

The implemented strategy consisted of seven key stages. These are described in Table 2. The activities were largely based on perception (Figure 15) where “graphical libraries” (Storer, 2008) were constructed and communicated based
on perceived visual stimuli. It should be noted that the researcher attempted to expand the activities further towards memory and imagination during the “Amalgamation” and “Conceptual Challenge Exercises”. The researcher delivered instruction for each activity.

![Figure 15 – Distinctions between drawing and sketching](image)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction Task (Reflection)</td>
<td>Encourage participants to engage in self-reflection and determine aspects of freehand drawing that they feel they perform well and aspects that they feel they need to improve on.</td>
</tr>
<tr>
<td>Perception Proof</td>
<td>Develop the ability to recognise and communicate both regular and irregular geometry using an inverted line drawing.</td>
</tr>
<tr>
<td>Perception Enhancement</td>
<td>Develop the ability to enquire into subtle geometry composed within a physical composition.</td>
</tr>
<tr>
<td>Space Enlightenment</td>
<td>Develop the ability to deconstruct a physical composition by analysing and communicating the spaces surrounding the physical entities.</td>
</tr>
<tr>
<td>Amalgamation</td>
<td>Develop the ability to harness the previously developed skills in communicating a physical composition, part of which was drawn from memory.</td>
</tr>
<tr>
<td>Realisation</td>
<td>Develop the ability to enhance sketches and communicate 3D form through rendering techniques that utilise a range of values.</td>
</tr>
<tr>
<td>Post-Instruction Task (Conceptual Challenge)</td>
<td>Develop the ability to synthesise conceptual elements and incorporate these into a self portrait composition.</td>
</tr>
</tbody>
</table>

### 3.2.3 Summary of Findings

A summary of key findings for Preliminary Study 1 are presented in this section.

#### 3.2.3.1 Key findings for the investigative focus group

- All of the eighteen participants sketched for fun from an early age.
• The environments in which the participants commonly sketched varied.
• Something always stimulated participants’ interest before beginning a sketch.
• Ten participants classified themselves as being fidgety people.
• Thirteen participants claimed that they did not notice time when sketching.
• Everybody described themselves as being thinkers with a tendency to notice unusual patterns.
• Nine of the participants reported periods of anxiety.
• Eight participants described themselves as being dyslexic.
• Eight participants preferred to draw intricate detail while seven participants preferred to concentrate on outline edges and relationships.

3.2.3.2 Key findings for the applied test group

• The findings of this initial study indicated that the ability to freehand draw was a learnable skill. There was significant evidence of improvement in participants’ command of orthogonal projection and their ability to communicate creative conceptual compositions. This is evidenced in the compositions where for example, Participant 4 drew his portrait from observation and then imagined himself as an astronaut in space (Figure 16) while Participant 5 imagined himself in a fish bowl (Figure 17).
Figure 16 – Participant 4 drawings from Preliminary Study 1

Figure 17 – Participant 5 drawings from Preliminary Study 1
• It was found that the techniques applied by Edwards (1989) were very complex and technical in nature and that they may pose difficulties for second level pupils.

• Participants expressed difficulty and concern when using a plastic 3D to 2D conversion plane during the Perception Enhancement exercise. Subsequently a set of picture planes (Figure 18) were designed. These were easy to use, hands-free, could be instantly cut on a laser machine and could be folded into a flat pack. The device was based on an invention by German Renaissance artist Albrecht Dürer and aids drawing in both perspective and proportion.

• Sketching from memory and imagination are two dimensions of drawing that were not considered within Edwards’ strategy (1989). Based on activities which were devised by the author, it was felt that these require development if sketching is to be used as a tool for design and problem solving in technology based subjects.

• The study was carried out in a fifteen hour timeframe but indications suggest that a shorter period of time is possible if activities were designed specifically by taking the participants, learning outcomes and incubation periods into account.

• Although the findings were very positive, it was felt that further research with a larger sample size that have an even greater variance in drawing/sketching ability was required.

Figure 18 – Hands free picture planes designed by the author
3.2.4 Conclusions

There were significant indications that the ability to freehand draw was teachable. The progression away from observational drawing towards conceptual type sketching proved difficult for participants although there was evidence that this progression was possible. The findings from the focus group proved very insightful and these informed the design of future studies involving large class sizes.

3.3 Preliminary Study 2

3.3.1 Overview

The purpose of this study was to validate some ideas for activities which aid in the development of freehand drawing ability while also reducing the amount of instruction time from Preliminary Study 1. Reducing the amount of time was seen as critical in order to determine the core skills for required for developing sketching expertise. The study was carried out with a group of novice undergraduate sketchers over a ten hour period. The design of the activities for the study took cognisance of the investigative focus groups’ feedback of sketching as a “fun” activity where they have freedom to sketch what they are interested in. Additionally, the activities were modified to include drawing aids which were specially designed as a result of concerns expressed by some participants during Preliminary Study 1.

The study was carried out with seven participants over eight hours during a three day period and instruction was provided by the researcher.
3.3.2 Methodology

3.3.2.1 Participants

The participants chosen for the study included six fourth year undergraduate students of technology education and one newly qualified teacher. The newly qualified teacher was selected as a participant as it was anticipated that he would deliver instruction to a large group of students during Preliminary Study 3. All participants rated their pre-instruction freehand drawing/sketching ability as poor or very poor and had expressed a keen interest in undertaking sketching instruction on a number of occasions. The group consisted of five males and two females.

3.3.2.2 Strategy

This study explored the effectiveness of activities which were revised based on the findings of Preliminary Study 1. A summary of the modifications/improvements made to the activities is described in Table 3. A detailed description of the rationale and method for each stage is provided in Table 4.

Table 3 – Summary of modifications to sketching activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflection</td>
<td>No modifications made</td>
</tr>
<tr>
<td>Perception Proof</td>
<td>The image was projected on to a large screen. This forced the participants to scale geometries. In Preliminary Study 1, participants copied from a sheet placed beside them. The target sketch was a concept based car and increased in complexity. This was more closely related to technology education. In Preliminary Study 1, participants sketched a seated man.</td>
</tr>
<tr>
<td>Perception Enhancement</td>
<td>The newly designed 3D – 2D conversion device (Figure 18) was utilised. Participants were given autonomy to construct their own novel physical composition. In Preliminary Study 1, participants used a floating 3D – 2D conversion device to sketch their hand.</td>
</tr>
<tr>
<td>Space Enlightenment</td>
<td>The physical composition became a side profile of a fellow participant. The technically difficult strategy described by Edwards’ (1989) was discarded. Participants were afforded the opportunity to enhance their sketch and add a conceptual element if they wished.</td>
</tr>
<tr>
<td>Conceptual Challenge</td>
<td>Rather than forcing the participants to sketch a self portrait and integrate a conceptual element (as in Preliminary Study 1), the participants were monitored closely on their ability to communicate a self portrait.</td>
</tr>
</tbody>
</table>
Table 4 - Description of stages for Preliminary Study 2

<table>
<thead>
<tr>
<th>Stage 1 – Pre-Instruction (Reflection Exercise)</th>
<th>Rationale</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The purpose of this preliminary activity was to encourage participants to analyse their drawing ability and to identify areas for improvement. The composition that participants completed was used as a comparator at the end of the study to establish whether there was an improvement in drawing/sketching skill.</td>
<td>Participants were provided with a mirror and sketchpad. They were required to look at themselves in the mirror and communicate the composition in whatever way they wished through a freehand drawing.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage 2 – Perception Proof Exercise</th>
<th>Rationale</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This activity was a significant progression of Edwards’ (1989) “Upside Down Drawing” which was applied in Preliminary Study 1. The activity aimed to develop the participants’ ability to recognise and realise the variance within geometry. The activity was designed to be implemented with large class groups. It aimed to develop participants ability to:</td>
<td>A line drawing of a concept car (Figure 19) was presented to the participants using a data projector and screen. Participants were given an A4 blank sheet of paper (which contained a grid) and a “B” grade pencil (Figure 20).</td>
</tr>
<tr>
<td></td>
<td>• Analyse regular and irregular geometry in 2D compositions • Scale the geometry and sketch in proportion • Communicate the geometry and explore the relationships between different elements within the composition</td>
<td>A PowerPoint presentation was used to reveal each part of the grid with three minutes between each transition. Participants communicated the geometry as each square of the grid was revealed (Figure 19).</td>
</tr>
</tbody>
</table>

Figure 19 – Revealing the composition

Figure 20 – Equipment Required
<table>
<thead>
<tr>
<th>Stage 3 – Perception Enhancement Exercise</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This activity was a progression of Edwards’ (1989) “Modified Contour Drawing” exercise which was applied during Preliminary Study 1. The improvements were as follows:</td>
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<tr>
<td></td>
<td>• A picture plane stabiliser was designed which was “hands-free” (Figure 21). This made the task of drawing on the plane simple and not a source of anxiety as previously experienced by participants.</td>
</tr>
<tr>
<td></td>
<td>• The activity was intended to promote creativity and participants were encouraged to incorporate as many artefacts as possible.</td>
</tr>
<tr>
<td></td>
<td>The activity was designed to significantly enhance the analysis and enquiry into intricate geometries that exist within compositions.</td>
</tr>
</tbody>
</table>

![Figure 21 – Picture Plane Stabilising Device](image)

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants were given a selection of objects from which they created a physical 3D composition.</td>
</tr>
<tr>
<td>Participants then proceeded to draw their unique composition onto the picture plane (Figure 21) making sure that all intricate geometries were recorded.</td>
</tr>
<tr>
<td>Once the composition was recorded on the 2D picture plane, participants were able to transfer this to their sketch pads.</td>
</tr>
<tr>
<td>Participants were encouraged to constantly evaluate their sketch and relate it to the physical composition.</td>
</tr>
<tr>
<td>Stage 4 – Enlightenment Exercise</td>
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<tr>
<td>---------------------------------</td>
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</table>

<table>
<thead>
<tr>
<th>Stage 5 – Post-Instruction (Conceptual Challenge)</th>
<th>Rationale</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The purpose of this activity was to provide the participants with an opportunity to synthesise the skills that were developed in the previous activities through a self portrait composition.</td>
<td>Participants were given a brief to sketch their self portrait using just a mirror, sketch pad, pencil and eraser.</td>
</tr>
<tr>
<td></td>
<td>The activity was also used to establish the amount of time that it would take for participants to draw their self portrait and whether this would be feasible in a controlled environment in secondary schools.</td>
<td>The participants were advised to use all their previously developed skills to communicate the composition.</td>
</tr>
<tr>
<td></td>
<td>Due to time constraints it was decided to ignore the conceptual element for this study as this would be explored in the subsequent preliminary study.</td>
<td>No time limitation was placed on the activity as this was an underlying question which required an answer.</td>
</tr>
</tbody>
</table>
3.3.3 Key Findings

- The findings from Preliminary Study 2 indicated that freehand drawing was a teachable skill as all participants claimed improvement in their own ability after receiving instruction. This was evidenced in examples of participants’ work in Figure 22 and Figure 23 where there was improvement in the participants’ ability to communicate in proportion with significant realism.

Figure 22 – Preliminary Study 2 Participant 1 Sketches
- A variation in drawing styles between participants was observed (Figure 24). Note the cartoon style depiction created by Participant 03, the bold dark values communicated by Participant 05 and the photograph-like drawing by Participant 07. These unique styles were interesting as they signified that the activities promoted and encouraged individual preferences and techniques.

Figure 24 – Examples of different participant drawing styles
• The implementation of the new novel and original 3D to 2D conversion device proved significant with participants able to compose creative 3D compositions and extract the geometries utilising the picture plane.

• The Enlightenment exercise which incorporated a conceptual theme proved enjoyable but time management was an issue and this required revision in future studies.

• The “Perception Proof” activity which utilised other ICT proved worthwhile but time management was an issue as the participants found that time given was too short to complete the composition. It was suggested that a composition of less complexity be used in future studies.

• The preciousness of participant compositions became very evident and although this can be considered as a positive finding, it was acknowledged that it could hinder progression towards developing sketching as a “sense making tool” (Jonson, 2005).

• The participants’ behaviour during each activity was slow, controlled and reflective.

• The compositions generated by all participants are illustrated in Appendix 5 (Volume 2).

3.3.4 Conclusions

Preliminary Study 2 provided further evidence that the ability to freehand draw is a teachable skill. The complex, personal nature of the skill was evident in the drawing/sketching styles of the participants. The implementation of novel activities to alleviate the anxiety surrounding the technical nature of some of Edwards (1989) activities proved successful.

It should be considered that all participants in both Preliminary Study 1 and 2 were very interested in developing their ability to draw/sketch. In order to establish the effectiveness of the evolving strategy in developing the ability
to freehand sketch, it was decided to implement the model of activities through a year three, graphics based module with a cohort of 124 undergraduate students. This is described in the next section.

3.4 Preliminary Study 3

3.4.1 Overview

Preliminary Study 3 was carried out with a cohort of 124 undergraduate students of a year three technology education programme. The study aimed to evaluate the effectiveness of a proposed model of activities for developing both “drawing” and “sketching” skills through a whole class teaching approach.

It was considered important to examine the effectiveness of implementing the strategy through whole class teaching as this was the challenge that practicing teachers are faced with in second level classrooms. It was also necessary to identify any trends in how students performed in the activities and independent cognitive tests as this would provide indicators for further development of the model of strategic activities.

During Preliminary Studies 1 and 2, the role of the researcher was to plan, implement and provide instruction to participants. In addition to this, the researcher was centrally involved in evaluating the strategy in collaboration with the participants. The researcher did not have a teaching role during Preliminary Study 3. Instead, a postgraduate student who participated in Preliminary Study 2 provided the instruction. It was anticipated that this would provide indications as to whether the model of activities could be taught by an independent teacher. The researcher collaborated with and
advised the postgraduate student in addition to observing classroom activities and collecting participant data.

The objectives for Preliminary Study 3 were as follows:

- To establish if the ability to freehand draw could be developed by an independent teacher.
- To explore the effectiveness of the activities which had evolved subsequent to Preliminary Studies 1 and Preliminary Study 2.
- To establish if the strategy was effective in developing drawing/sketching abilities of large class groups with variations in interest levels and abilities.
- To establish any underlying cognitive attributes which predicate high levels of performance in sketching based activities.

3.4.2 Participants

124 third year undergraduate students of teachers of technology education participated in Preliminary Study 3. Their age ranged from 21-36 and the cohort had only two female participants which was approximately 2% of the overall cohort.2

Prior to taking part in the strategy, all students were required to rate their level of sketching ability (Figure 25) and provide details of graphical subjects studied at second level (Figure 26). It was notable that 57 students rated their sketching ability as either “poor” or “very poor” while 32 students rated their sketching ability as “average”.

2 According to a recent Chief Examiners (S.E.C., 2009b) report the number of males taking DCG at second level is significantly more than females where males account for 91% of the overall cohort and females at 9%. 
All students were required to take part in the activities as these formed a core element of their module of study which aimed to develop the necessary competencies to engage in conceptual design based activities. Each class was two hours in duration and the time of day in which these took place varied.
3.4.3 Design of Study

The overall design of Preliminary Study 3 was broken down into three main sections (Figure 27). In order to establish the effectiveness of the strategy it was necessary to incorporate various measures into the design of the study. Prior to considering the assessment techniques applied, the design of the applied strategy is described briefly.

![Figure 27 – Breakdown of the design of Preliminary Study 3](image)

3.4.3.1 Applied Strategy

The applied strategy was broken into seven (Figure 28) stages which were all unique, yet complementary activities that had specific learning outcomes (Table 5). The activities were strategically devised based on the findings of Preliminary Studies 1 and 2. Instruction was provided over four, two hour periods with appropriate incubation periods of one week.

![Figure 28 – Breakdown of activities Preliminary Study 3](image)
Table 5 provides a brief description and summary of the learning outcomes associated with the activities within Preliminary Study 3.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction Task (Reflection)</td>
<td>Similar to Preliminary Studies 1 and 2. Students drew their self-portrait in</td>
<td>Students were able to engage in self-reflection and determine aspects of</td>
</tr>
<tr>
<td>(45 minutes)</td>
<td>an exploratory type activity.</td>
<td>sketching that they felt they performed well and aspects that they felt they needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to improve on.</td>
</tr>
<tr>
<td>Recognition (60 minutes)</td>
<td>The activity facilitated students in drawing an irregular composition</td>
<td>Students were able to perceive, recognise, scale and synthesise relationships.</td>
</tr>
<tr>
<td></td>
<td>utilising scale, proportionality and relationships. The composition was</td>
<td></td>
</tr>
<tr>
<td></td>
<td>presented to the class using a data projector and a screen measuring 4m x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3m. Students drew the composition on an A4 sheet.</td>
<td></td>
</tr>
<tr>
<td>Enquiry (90 minutes)</td>
<td>A perception enhancement exercise was used to develop student’s ability to</td>
<td>Students were able to construct a physical composition, sketch accurately in</td>
</tr>
<tr>
<td></td>
<td>graphically represent a 3D composition on a 2D picture plane.</td>
<td>perspective, appreciate the gestalt, critique and suggest improvements.</td>
</tr>
<tr>
<td>Transfer (45 minutes)</td>
<td>The activity engaged the students in the skill of physically sighting a</td>
<td>Students were able to determine a suitable scale, communicate relationships and</td>
</tr>
<tr>
<td></td>
<td>composition and further developing skills.</td>
<td>values, apply sighting technique, comprehend principle of picture plane.</td>
</tr>
<tr>
<td>Enlightenment (60 minutes)</td>
<td>This was a new activity that enabled the students to create a physical</td>
<td>Students were able to compose a creative physical composition, determine the best</td>
</tr>
<tr>
<td></td>
<td>composition which they drew from memory.</td>
<td>viewing position, analyse and determine critical information, utilise thumbnail</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sketches and annotations, communicate critical information, sketch from memory.</td>
</tr>
<tr>
<td>Post-Instruction task (Journey)</td>
<td>The activity facilitated students in imagining themselves in a conceptual</td>
<td>Students were able to develop a conceptual theme, synthesise previously developed</td>
</tr>
<tr>
<td>(90 minutes)</td>
<td>composition and they represented this in a drawing that harnessed previously</td>
<td>skills, evaluate and critique the completed composition.</td>
</tr>
<tr>
<td></td>
<td>developed skills.</td>
<td></td>
</tr>
<tr>
<td>Unification (60 minutes)</td>
<td>This was a new activity which enabled students to explore principles and</td>
<td>Students were able to explore geometric problems using freehand sketching a sense</td>
</tr>
<tr>
<td></td>
<td>problems in plane and descriptive geometry through the medium of sketching.</td>
<td>making tool. The sketching process became maximally automatic at this stage.</td>
</tr>
</tbody>
</table>

As illustrated in Figure 27, Preliminary Study 3 consisted of three stages, two of which were concerned with assessment. These are discussed in the next section.
3.4.3.2 Assessment Strategies

The effectiveness of the applied strategy was measured using three methods. These methods (Figure 29) were specifically selected with the aim of evaluating the students learning experience, establishing the cognitive factors associated with expertise in freehand sketching and examining the development (if any) in students ability to freehand sketch using an online assessment.

![Diagram: Student Feedback, Cognitive Measures, Online Assessment]

Figure 29 – Assessing the applied strategy in Preliminary Study 3

**Student Feedback**

In order to gain an insight into the students learning experience, all students were required to rate their performance at the end of each activity (Appendix 6.1, Volume 2) and also rate the value that they placed in the activities. The students were also asked to provide any additional feedback on their experiences and indicate areas of freehand sketching that they would like to develop in future studies.

Students were asked to evaluate their level of progression during and at the end of the study along a Likert scale where a range of possible responses were given to each question.
Cognitive Measures

The Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976), was utilised at the end of the study in order to identify any underlying factors that may be influencing participant performance during sketching activities. Factors that were assessed include:

- **CS – Speed of Closure**: “The ability to unite an apparently disparate perceptual field into a single concept”.
- **FF – Figural Fluency**: “The ability to draw quickly a number of examples, elaborations or restructurings based on a given visual or descriptive stimulus”.
- **VZ – Vizualisation**: “The ability to manipulate or transform the image of spatial patterns into other arrangements”.
- **XF – Figural Flexibility**: “The ability to generate new and different solutions to figural problems” (Ekstrom et al., 1976).

After careful consideration, the above factors were selected for assessment based on the description provided (Ekstrom et al., 1976) and indicators in research on visual imagery (Kosslyn, 1998), visualisation and spatial ability (Gaughran, 1990, Olkun, 2003) which can be related to freehand sketching.

The results of these tests were correlated with performance scores in sketching based activities. This then provided an indication as to how future activities could be designed to maximise performance in sketching activities.

**Online Assessment**

The development of participant’s skills was evaluated by both participants themselves and a team of independent subject and non-subject specialist assessors through an online survey (Appendix 6.2, Volume 2).
The team of independent assessors completed the online survey by ranking levels of:

- **Improvement** from pre-instruction to post-instruction
- **Likeness** between a profile photograph and the post-instruction composition
- **Creativity** of the post-instruction composition (Figure 30)

The above variables were assessed based on a ten point semantic differential scale (Cohen, 2007). Similar criterion-referenced methods for assessing sketching skills have been utilised by Yang (2007) and Goldschmidt and Smolkov (2006).

### 3.4.4 Findings

The following were the main findings for Preliminary Study 3;

- Visual analysis of all pre and post instruction sketches that were completed by students during Preliminary Study 3 provided significant evidence of improvement in student’s ability to freehand sketch. A selection of students’ pre and post-instruction sketches are illustrated in Figure 31. Generally, there was a notable improvement in students’ ability to communicate realistically, creatively and conceptually in their post-instruction compositions.
Students placed significant value in the activities. Based on the pre and post-instruction self ratings; there was a statistically significant difference (\(p=0.001\)) in students sketching ability.

Based on the results of the cognitive measures and online assessment, there were significant indications that expertise in freehand sketching is associated with high levels of figural flexibility and creativity.

There was notable evidence within student sketches and from classroom observations of a high degree of preciousness in the sketches that were produced. Students’ behaviour was observed to have been slow, controlled and reflective. Further research would examine how these skills could become automatic and reflective in nature resulting in sketching becoming a “sense-making tool” (Jonson, 2005).

It was found that the independent teacher was very competent in delivering instruction for each activity which further validated the effectiveness of the model of activities.

All participant pre and post-instruction compositions for Preliminary Study 3 are presented in Appendix 7, Volume 2.
3.4.5 Conclusions

Following the large scale Preliminary Study 3 it was concluded that it was possible to teach large class groups to freehand draw. However, the activities were still largely focused within the observation component of the continuum (Figure 32) with some exploration of memory and conceptual sketching skills being evidenced.

![Figure 32 – Continuum of progression between drawing and sketching](image)

3.5 Research questions arising from the Preliminary Studies

Although the Preliminary Studies provided a platform towards meeting the objectives for the overall study, there were a number of research questions which still required investigation. These are outlined as follows:

1. There were significant indicators from the Preliminary Studies that suggested the ability to freehand draw was a teachable skill. The application of pre and post instruction tasks provided an appropriate means for measuring participant development although the assessment of these was subjective in nature. The Primary Research Study required an additional method to support these initial findings.
2. Through the proposed model of strategic activities it was evident that the ability to freehand draw could be developed and the freehand sketching skill to a slightly lesser extent. However, there was evidence of predominantly controlled, reflective drawing/sketching behaviour throughout the Preliminary Studies. The model required further revision for implementation in the Primary Research Study in order to promote more automatic, reflexive behaviour through conceptual type sketching activities.

3. While the approach during the Preliminary Studies was very positive there was insufficient evidence to validate that the model of activities was effective in developing core sketching competencies. This needed to be addressed in a comprehensive study through the application of suitable methods that capture the tacit and implicit nature of sketching behaviour and cognition.

3.5.1 Research Hypothesis

Based on the literature presented in Chapter 2 and the findings of the Preliminary Studies, the research hypothesis for the Primary Research Study was as follows:

Hypothesis

“It is possible to develop the ability to freehand sketch through appropriate instruction. A model of strategic activities which promote the development of core competencies for drawing and sketching can be designed, implemented and its effect can be empirically examined.”
4 PRIMARY RESEARCH STUDY
4.1.1 Overview

The findings from the Preliminary Studies provided evidence that the ability to freehand draw was a teachable skill. Building on these findings, the purpose of the Primary Research Study was to apply a revised model of activities which promoted freehand drawing skills in addition to conceptual sketching skills. It was also important that the effectiveness of the activities which embraced the “observation” to “imagination” continuum (Fish, 1990) should be examined through appropriate methods in order to understand any development in student’s sketching skill, cognition and behaviour.

There were a number of key objectives that the Primary Research Study aimed to address. These included the following:

1. To select and apply a valid and reliable method for measuring the development of students ability to freehand sketch as a result of participating in the model of activities.
2. To further evaluate student’s development by examining their cognition and sketching behaviour through appropriate measures.
3. To evaluate the effectiveness of a model of drawing and sketching activities through the voices and perspectives of the students by applying various quantitative and qualitative methods.

The above objectives informed the approach taken to design the method for the Primary Research Study. This approach is described in the next section.
4.2 Research Approach

In order to establish any development in student’s ability to freehand sketch as a result of completing the model of activities, it was decided that a number of pre-tests and post-tests (Cohen et al., 2007) would be conducted (Figure 33). As the focus of the study was to develop freehand sketching skills it was decided that any pre and post-instruction tests would incorporate conceptual elements. This was important in order to establish if students were able to utilise freehand sketching as a tool for retrieving, manipulating and synthesising “graphical libraries” (Storer, 2008).

Verstijnen et al. (1998b) argues that a valid scientific argument is required in order to validate any model of instruction which claims to promote the ability to freehand sketch. Considering the tacit and implicit nature of sketching skill it was difficult to identity an independent valid and reliable test capable of measuring holistic development. Literature concerning expertise in freehand sketching identifies some methods that have the capacity for measuring different elements of sketching behaviour and cognition. These include criterion referenced assessment (Yang, 2007, Goldschmidt & Smolkov, 2006), cognitive tests (Finke, 1990) and visual and verbal protocol analysis (Middleton, 2008). The design and implementation of these tests was considered in terms of their appropriateness for assessing
any pre and post-instruction sketches, student’s cognition and sketching behaviour.

4.2.1 Examining Pre and Post-Instruction Sketches

At this stage, the details of any pre and post-instruction conceptual sketching tasks had not been decided. The literature presented in Chapter 2 considered two research studies that applied criterion referenced assessment to examine the sketching skills of designers. Yang (2007) applied a number of criteria in assessing the influence of instruction on sketching skill in engineering design. Goldschmidt and Smolkov (2006) investigated the impact of external representations on participants design thinking and sketching performance by also applying a form of criterion referenced assessment. Although this type of assessment had its merits several concerns were identified. These included the following:

1. How would specific criteria be identified for pre and post-instruction sketching tasks if they were conceptually based?
2. How would validity and reliability be addressed in the assessment of conceptual sketches?

Further analysis of literature surrounding the assessment of creative design based activities identified a solution for these concerns in terms of “Comparative Pair’s Assessment” (Kimbell, 2008). This is a novel approach to assessment that simply involves examiners looking at a pair of “scripts” and making a judgement on those as to which one is “better” (Kimbell, 2008). The method is derived from Thurlstone’s (1927) “Law of Comparative Judgement”; where two performances are compared by a judge based on their own internalised criteria and, if consistent, the judges standards cancel each other out. Based on the assessments made, a ranked order is generated by sophisticated software. The holistic nature of “Comparative Pairs Assessment”
makes the process much simpler when judgements can be made based on the better demonstration of sketching ability.

In summary the application of “Comparative Pairs Assessment” provided the following:

- It results in the ordering of data from “best” to “worst”. If the process is capable of ordering data, then it was capable of sorting pre and post-instruction conceptual sketches.
- Rather than applying specific criteria and making judgements on bits and pieces of each sketch and then adding them up, “Comparative Pairs Assessment” allows judgements between two randomly selected sketches to be made as a whole. The criteria that each judge applies for each decision could be determined thereafter.
- Validity could be addressed by the capability of the candidates, in terms that specialist and non-specialist assessors agree that a resulting rank order is a true reflection of student performance.
- Reliability or repeatability could be addressed by overall agreement between judges.
- The magnitude of student development could be measured by the difference between the pre-instruction and post-instruction sketches of each student within a generated rank.

At this point it was decided that some type of a pre and post-conceptual sketching task would be assessed by “Comparative Pairs Assessment”. However, this method of assessment was only used to examine externally represented sketches. In order to examine any change in student’s cognition as a result of completing the model of sketching activities it was necessary to investigate literature which describes the measurement of various cognitive factors. This is presented in the next section.
4.2.2 Examining Cognitive Development

In order to understand the cognitive attributes of expert sketchers one must refer to research (Finke, 1990, Reed & Johnsen, 1975, Verstijnen, 1998b) relating to visual mental imagery where freehand sketching was used as a medium in experiments relating to creative discovery through combining and restructuring tasks. It has been found that expert sketchers perform better in “restructuring” tasks that involve the decomposition of a component into incidental parts (Verstijnen, 1998b).

During Preliminary Study 3 a cognitive test was applied where there were indications that success in freehand sketching activities was associated with “Figural Flexibility” and in particular, students performance in the “Storage Test” (Elkstrom et al., 1976). “Figural Flexibility” (Elkstrom et al., 1976) is the ability to generate new and different solutions to figural problems. This is similar to “restructuring” (Verstijnen, 1998b). It was decided that the test of “Figural Flexibility” would be applied again in the Primary Research Study.

In addition to the application of the storage test, it was decided that a battery of tests from the cognitive factor of “Induction” should be applied. These identify the kind of reasoning abilities involved in forming and trying out hypotheses that will fit a set of data (Elkstrom et al., 1976). “Induction” is composed of three tests which include; “Letters Test”, “Locations Test” and “Figural Classification Test”. It was decided to apply these tests based on research (Kavakli et al., 1999) that associates sketching expertise with the ability to form links between different spatial features in a sketch. Also, the findings of the investigative focus group in Preliminary Study 1 indicated that expert sketchers notice unusual patterns while sketching and Jonson (2005) describes sketching as a “sense making tool”.
Bearing in mind that psychomotor tests generally evaluate specific cognitive factors, it was necessary to consider some other measure which would provide an insight into the more complex nature of sketching behaviour. This is examined in the next section.

4.2.3 Examining Sketching Behaviour

Suwa et al. (1998b) describe sketching ability as being tacit and implicit in nature. In order to capture the complexity of the cognitive actions involved during any conceptual sketching episodes, a scientific measure was essential. Visual and verbal protocol analysis provides a rich source of data in relation to how people deploy a range of cognitive procedures and behaviours during specific tasks (Middleton, 2008).

Little research has been conducted using visual and verbal protocols to examine development of sketching expertise. However, notable research (Suwa et al., 1998b, Middleton, 2008, Kavakli, 1999) has been carried out within design education to examine the cognitive actions of designers during sketching based activities.

Given the clear breakdown of cognitive actions provided by Middleton (2008), it was decided to apply this scheme through some sort of pre and post-instruction design based sketching tasks. The main purpose of its application was to establish whether there was any difference in sketching behaviour in students as a result of completing the model of sketching activities. In addition to this, the data could be analysed to provide a more scientific insight into the broader, complex cognitive actions of students and the type of sketches that they produced.
An overall summary of the approach for designing the Primary Research Study is as follows:

- The study would be composed of three elements which included pre-tests, the application of the model of sketching activities and post-tests.
- Comparative Pairs Assessment (Kimbell, 2008) would be used to measure pre and post-instruction conceptual sketches.
- A battery of psychometric tests would be used to measure any development in student’s cognitive factors of “Figural Flexibility” and “Induction” (Elkstrom et al., 1976).
- Visual and Verbal Protocol Analysis (Middleton, 2008) would be used to examine any development in sketching behaviour through pre and post-instruction design based sketching tasks.

Prior to considering the design of the study the research participants are described in the next section.

4.3 Research Participants

The participants for the Primary Research Study were all year three undergraduate students of technology education. These were a new group of students who were not involved in the Preliminary Studies. In total, 134 students participated in the research which was carried out as a core element of a Design and Communication Graphics module similar to the module described in Preliminary Study 3. The focus of the module of study was to enable students to bring their understanding of geometric concepts and principles on a journey, which explored ill-defined geometric problems within a design driven environment through the medium of freehand sketching.
All but one of the students was male. The undergraduate students of teacher education at University of Limerick are composed of two groups based on their course of study. 56% of students were part of the “Materials and Construction Technology” group and 44% from the “Materials and Engineering Technology”. The descriptive statistics for the student’s ages is presented in Table 6.

<table>
<thead>
<tr>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>134</td>
<td>19</td>
<td>36</td>
<td>20.91</td>
</tr>
</tbody>
</table>

Prior to commencing the sketching activities all students were given the opportunity to take part in an additional element of the research. This element involved students thinking aloud while solving a given technological brief through the medium of freehand sketching. Forty-one students volunteered all of whom were male. 71% of students were part of the “Materials and Construction Technology” group and 29% from the “Materials and Engineering Technology”. The descriptive statistics for the student’s ages is presented in Table 7.

<table>
<thead>
<tr>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>41</td>
<td>19</td>
<td>27</td>
<td>21.86</td>
</tr>
</tbody>
</table>

All participants provided preliminary information on their previous graphics experience at second level and their interest in developing their ability to graphically communicate through freehand sketching. Figure 34 and Figure 35 illustrate the results for the entire cohort.
93% of the entire cohort claimed they were either “somewhat interested” or “very interested” in developing their ability to freehand sketch. 58% of students studied Technical Drawing\(^3\) (Senior Cycle) at higher level while 18% never studied graphics at second level.

\(^3\) “Technical Drawing” was the predecessor to “Design and Communication Graphics” (DCG)
The next section of the chapter presents the overall design of the study based on the approach described in Section 4.2.

4.4 Design of Primary Research Study

4.4.1 Overview

The study was composed of three main sections (Figure 36) which included the following:

1. Pre-Tests – Conceptual Sketching Tasks, Psychometric Tests and Visual and Verbal Protocol Analysis
2. Continuum of drawing and sketching activities
3. Post-Tests – Same as Pre-Tests

The three vertices for each triangle represent each test at pre and post-instruction. The results of these tests were subsequently triangulated in order to fully comprehend any development in sketching skill, student cognition and sketching behaviour. The study took five weeks to complete with a total of eight hours instruction time. The timeline is also presented in Figure 36 where lecture and laboratory times are detailed in addition to what data were collected.
Figure 36 – Design of Primary Research Study

Timeline

**Week 1 (Pre-Instruction Tests)**
Visual and Verbal Protocols
Psychometric Tests
Conceptual Sketching Task

**Week 2**
Lecture Time: 1 hour
Task: Recognition... Data collected: Student sketches, Student performance, Value placed in activity & Qualitative Feedback

Lab Time: 2 hours
Task: Auxiliary Recognition, Enquiry and Auxiliary Enquiry ... Data collected: Student sketches, Student performance, Value placed in activity & Qualitative Feedback

**Week 3**
Lecture Time: 1 hour
Task: Transfer... Data collected: Student sketches, Student performance, Value placed in activity & Qualitative Feedback

Lab Time: 2 hours
Tasks: Auxiliary Transfer, Enlightenment and Auxiliary Enlightenment... Data collected: Student sketches, Student performance, Value placed in activity & Qualitative Feedback

**Week 4**
Lab Time: 2 hours
Tasks: Journey (a) & (b) and Auxiliary Journey... Data collected: Student sketches, Student performance, Value placed in activity & Qualitative Feedback

**Week 5 (Post-Instruction Tests)**
Visual and Verbal Protocols
Psychometric Tests
Conceptual Sketching Task
As the model of sketching activities was central in developing students ability to freehand sketch, its design is described in the next section.

4.4.2 Model of Sketching Activities

The model of sketching activities (Figure 37) was informed by the research literature presented in Chapter 2 in addition to the findings of the Preliminary Studies. The model was designed so that progression was from left to right. The perception focused activities in the beginning were designed to promote fundamental freehand drawing skills. The memory focused activities were devised to facilitate the shift from observational drawing to conceptual sketching. Finally, the conceptual based activities on the right promote the development of skills where sketching becomes a conceptual journey (Hope, 2008).

In its progression, towards the conceptual activities on the right, sketching skills are synthesised into a maximally reflexive and automatic state (Satpute, 2006, Stillings, 1995). The progression from left to right represents the dichotomy between Goldschmidt’s (1991, 2003) “seeing-as” and “seeing-that” modalities of sketching. The nature of cognitive activity at the left of the model is “controlled and reflective” and towards the right hand side it become “automatic and reflexive” (Stillings, 1995) in nature.
A brief description for each activity within the model is given in Table 8 while a comprehensive description of the rationale and application of each activity is provided in Appendix 1.

At the end of each of the core activities, the students were asked to rate their sketching performance\textsuperscript{4} and the value\textsuperscript{5} they placed in the activity in addition to providing any feedback comments. All students’ sketches from the model of activities were also assessed by the researcher\textsuperscript{6} in order to provide an alternative measure of performance. The sketching activities were conducted during both lectures and laboratory sessions (Figure 38). Similar to Preliminary Study 3, a postgraduate student provided instruction to all students during the laboratory based activities. The module lecturer delivered instruction during the lecture based activities.

\textbf{Figure 38 – Different sketching environments}

\textsuperscript{4} \textbf{Performance} was measured along a ten point scale where 1=Very Poor and 10=Very Good

\textsuperscript{5} \textbf{Value} was measured along a ten point scale where 1=No value and 10=Significant Value

\textsuperscript{6} \textbf{Researcher scores} were based on quality of sketching and creativity where 1=Very Poor and 10=Very Good
Table 8 – Brief description of each activity within the model

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>The purpose of this observational drawing activity which was conducted in a lecture environment was to enable students to analyse the relationships between regular and irregular geometries presented on a large screen (using a reference grid) and present these through a scaled composition.</td>
</tr>
<tr>
<td>Enquiry</td>
<td>This observational drawing based activity was designed to aid students in drawing a composition of physical 3D geometric models. The students used a specially designed 3D to 2D conversion device to trace the image of each geometric model on to a picture plane. The students then used the skills developed in the previous two activities to transfer the composition from the picture plane to paper.</td>
</tr>
<tr>
<td>Transfer</td>
<td>This activity was somewhat similar in nature to Recognition as it took place in the lecture setting and a composition was presented to the students using a large screen. However, the time was reduced for this activity, the composition was more complex and detailed, no grid reference was given and the students had to conceptually represent a cast shadow.</td>
</tr>
<tr>
<td>Enlightenment</td>
<td>This activity aimed to harness and synthesise the previously developed sketching skills through a series of memory exercises. Students were presented with five separate geometric configurations which they then had to communicate from memory.</td>
</tr>
<tr>
<td>Journey</td>
<td>This was composed of two activities which were conceptually based. Students were required to work in groups to solve conceptually derived briefs in short timeframes.</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>This activity was designed to facilitate the cognitive shift away from observational type sketching. The activity promoted students to use figural argumentation to produce a mirror image of presented line drawing. When the mirrored element was drawn, the students were afforded the opportunity to add a conceptual theme using a variety of media that were made available.</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>Similar to Enquiry, this activity involved the observational drawing of physical 3D artefacts. All students were given a pocket sized 3D to 2D conversion device which they used to record critical proportions and relationships of different artefacts. The aim of the activity was to develop student’s skills to draw a physical composition by imagining a picture and reducing the need to use the 3D to 2D conversion device. This was a task that the students were required to complete at home and they were given one week to complete it.</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>This activity was designed to promote the students ability to explore, manipulate and communicate the geometry of a simple paper pin. The students were presented with an image of the pin and they were then required to sketch as many orientations of it as possible during a twenty-five minute timeframe.</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>This activity was designed due to a number of concerns expressed by the students about their lack of confidence in rendering sketches. Students were presented with an outline figure which they had to sketch and then render using an example reference.</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>This activity was completed by each student individually. Students were given a number of abstract regular and irregular geometries. They were required to expand on and conceptualise each set of geometries. The only criteria students were given was that their ideas should be creative.</td>
</tr>
</tbody>
</table>
4.4.3 Conceptual Sketching Tasks

4.4.3.1 Rationale

Even though the results of the pre and post-instruction activities for the Preliminary Studies provide evidence of an increased ability to synthesise and communicate graphically through freehand sketching, the results are subject to varying levels of debate. Although the use of self-portraits as a comparative measure proved successful, some concerns were identified. These include the following:

- It was difficult to quantify any development in sketching ability by solely comparing pre and post instruction self portraits that were sketched by a student.
- Not all students may be comfortable drawing themselves and therefore might disengage in the activities.
- Time spent completing each self-portrait task during the Preliminary Studies was flexible as the majority of students took great pride in the post-instruction activity as they realised their developed ability to draw/sketch. Thus, direct comparison of the pre and post instruction compositions was not controlled.
- Superficially, the activities could be considered more closely related to art education rather than technology education.
- Communication of a self portrait during the Preliminary Studies proved to be an effective method of evaluating student’s development however; the task was primarily based around freehand drawing. As sketching within technology education is considered a tool for communication in addition to problem solving, this suggests that it should be primarily used in conceptual type tasks.

In order to inform the development of a suitable pre and post-instruction conceptual sketching task the literature was reviewed. A common theme

Based on the above descriptions, the sketching tasks for pre and post-instruction were designed. Cognisance was taken of the fact that the module in which the sketching activities were taking place was Design and Communication Graphics where the core elements were derived from constructed knowledge in plane and solid geometry. It was decided to focus the tasks around building on students prerequisite graphical libraries of geometric shapes and incorporate these into a conceptual activity. The following brief was given to the students for both the pre and post-instruction Conceptual Sketching Tasks:

- “Design a conceptual character based on the geometric shapes shown below (Figure 39). You must use each of the given shapes at least once. You may use additional shapes if you wish.”

Figure 39 – Given shapes for the Conceptual Sketching Tasks
4.4.3.2 Administering the Conceptual Sketching Tasks

The pre-instruction Conceptual Sketching Task was administered during the first module lecture that the students attended, prior to commencing any of the core sketching activities. Five weeks later, subsequent to the completion of the core model of sketching activities, the post-instruction Conceptual Sketching Task was administered (again in a lecture). The lecture environment (Figure 40) provided a suitable setting for controlling the reliability of the tasks.

Figure 40 – Lecture environment during Conceptual Sketching Tasks

Prior to being informed of the pre-instruction Conceptual Sketching Task, the students were asked to rate their sketching ability along a Likert Scale\(^7\) (Cohen et al., 2007). Subsequent to this, the students were allocated fifteen minutes to complete the task and critical observations were recorded by both the researcher and the module lecturer during this time.

Students were asked to rate their sketching ability at the end of the post-instruction Conceptual Sketching Task activity. This was rated along the same Likert Scale as for pre-instruction.

\(^7\) The following ratings formed the Likert Scale 1=Very Poor, 2= Poor, 3= Not Sure, 4=Good and 5= Very Good
Once all of the pre and post-instruction Conceptual Task sketches were gathered they were assessed using “Comparative Pairs Assessment”. This process is described in the next section.

4.4.3.3 Application of Comparative Pairs Assessment

Prior to inviting any judges to participate in the study, all pre and post-instruction Conceptual Sketching Task sketches for the entire cohort of 134 students were uploaded onto a secure server. All pre-instruction sketches were called “studentname1” and all post-instruction sketches were called “studentname2”. It should be noted that these filenames were only visible to the researcher who monitored the entire process. The sketches were then aligned with a special data base.

The 41 students who participated in the think aloud sketching activities (visual and verbal protocols) were selected as judges for the Comparative Pairs assessment. An additional 30 specialists who were external to the research study were also invited to participate as judges.

All judges were invited by email to participate. A five minute video was attached to the email. This described the tasks carried out and the assessment procedure. Each judge was given a unique user name and password if they agreed to participate.

The following is a summarised description for the judgement process:

- The judges were informed of the overall task that the students were required to carry out.
- The judges were guided through inputting the username, password and accessing the judgement session.
- The method of comparing different portfolios was described.
• Finally, the judges were instructed to comment on their judgement once they had made their decision. This qualitative feedback was critical for establishing the type of criteria that were applied.

In total, each judge made 37 judgements. All of the pre and post-instruction sketches were assessed together in the same round of judgements. When all judgements were made, a single rank order of the pre and post-instruction sketches was generated. Therefore, it was not possible for any student to have their pre and post-instruction sketch in the same rank position.

From the ranked order, it was possible to determine any improvement or disimprovement for each student by calculating the following;

\[
\text{Rank Shift} = \text{Post-Instruction Rank} - \text{Pre-Instruction Rank} \quad (6.1)
\]

Solely basing the improvement/disimprovement of students sketching ability on the amount of places moved between pre and post-instruction posed some concerns. For example; a student with a pre-instruction rank position of 20 only has the capacity to improve their rank position by 19 places. On the other hand a person with a pre-instruction rank position of 100 has the capacity to improve by 99 places. In order to further comprehend the magnitude of students’ improvement or disimprovement two weighted equations were developed. A weighted shift score took into account the difference between each student’s pre and post-instruction rank positions in addition to the amount of places that they could have moved within the rank. The first of these was applied to students who were classified as “positive movers” where their post-instruction rank was lower (better) than their pre-instruction rank.
Where \( n \) = number of people in list.

The following equation was applied for “negative movers” whose post-instruction rank was higher (worse) than their pre-instruction rank.

\[
\text{Weightedshift} = \frac{\text{postinstructionrank} - \text{preinstructionrank}}{\text{preinstructionrank} - 1} \times -n \quad (6.2)
\]

Where \( n \) = number of people in list.

The logic for equations 6.2 and 6.3 is explained in Appendix 2 together with an example for both a “Positive Mover” and a “Negative Mover”.

Finally all comments that the judges recorded were analysed and codified using an “open coding” (Cohen et al., 2007) procedure. This enabled the data to be explored in order to identify common feelings, actions, interpretations and so on for all judgements that were made. This provided an insight into the criteria that the judges applied. The next section describes the implementation of psychometric tests to measure the cognitive development of students.

### 4.4.4 Psychometric Tests

#### 4.4.4.1 Rationale

The reasons for applying and selecting psychometric tests as a measure of students cognitive development was described in Section 4.2.2. The main purpose of the tests was to establish if there was any development in student’s cognitive factors of “Figural Flexibility” and “Induction”. Four tests
were administered which included a “Storage Test”, “Locations Test”, “Letters Test” and “Figural Classification Test” (Ekstrom et al., 1976). The implementation of these is described in the next section.

4.4.4.2 Implementation

All students were required to complete the four psychometric tests (Figure 41) as part of the module requirements. In total the four tests when applied at pre and post instruction, took over two hours to complete.

As the “storage test” required students to record their answers on paper, it was decided to administer the test during lecture time where 10 minutes were allowed for its completion. The three tests within the “Induction” cognitive factor were implemented using an online assessment tool. Students were randomly divided into three groups and a unique link was sent to the students on three different days. The students were allowed to complete these tests at any time during a twelve hour period. The time that students spent doing the tests was recorded to ensure validity within the assessment.
4.4.5 Visual and Verbal Protocols

4.4.5.1 Rationale

The reasons for selecting Visual and Verbal Protocol Analysis (with the group of 41 students) as pre and post-instruction measure were described in Section 4.2.3. The main purpose of the method was to examine the sketching behaviour and cognition of students during a design based sketching task. The design of these tasks is described in the next section.

4.4.5.2 Design of Sketching Tasks

The sketching based design problems administered needed to meet a number of specifications similar to those defined by Middleton (2008). These included the following:

1. It had to be a problem that was related to the student’s course of study
2. The problem had to be authentic and of common interest to all students
3. The problem had to contain some features that would make it challenging for all students

Based on the above criteria, it was decided to refer to previous Leaving Certificate Technology coursework briefs8 (S.E.C., 2011, 2009a) and design tasks that the students carried out in previous modules9 (Seery et al., 2010) in order to design appropriate briefs for the visual and verbal protocols. The following two briefs were devised:

---

8 Technology coursework briefs describe a thematic problem that needs to be solved through the design and production of an artefact. The entire project is worth 50% of the students overall grade.

9 The design of both briefs contains an element relating to personalising the design for a specific purpose. All students have been experienced similar criteria in a previous module reported by Seery et al. (2010).
• Pre-Instruction: “Boiling water is an essential task that people carry out in everyday life. You are required to design an artefact for boiling water for a person you hold in high regard. The artefact must have some sort of an electrical or mechanical movement and it should be appealing to the person it is designed for”.

• Post Instruction: “Toys for young children are often attractive, exciting and robust. You are required to design a concept toy for a child that you know. The toy should incorporate mechanical or electrical movement and it should be appealing to the child it is designed for”.

4.4.5.3 Implementation

Based on the described briefs, the visual and verbal protocols were applied using the cohort of 41 students who volunteered to participate prior to commencement of the module.

Similar to the psychometric tests, the protocols took place at pre and post instruction, six weeks apart. Students were divided into groups that consisted of no more than six students at any one time. The sketching activities took place in a laboratory (Figure 42) in which the students commonly engaged in creative activities.
Each student was given a headset to record verbal “think aloud” (Middleton, 2008) actions while a webcam was set up to discretely record the visual sketching actions during the sketching process. A computer screen was positioned in front of the students so that they were aware of what was being recorded (Figure 43). Prior to the commencement of both the pre and post instruction protocols, instruction was given to students on how to “think aloud” and the students were also required to trial the equipment.

The students were allocated twenty minutes to complete the activity and were reminded throughout to keep verbalising their thoughts. The twenty minute timeframe was based on the length of similar sketching tasks described by Goldschmidt and Smolkov (2006). When the activity concluded, all videos were saved to a data base and all hardcopy drawings were filed away.
4.4.5.4 Analysing the Visual and Verbal Protocols

Subsequent to collecting the visual and verbal protocols data, all of the videos were examined, the verbal data were inputted and coded and the relationships between the visual and verbal data was analysed.

The continuously recorded video files were transcribed and broken down into segments. The length of the segments was determined based on the smallest unit of meaning that suggested one cognitive action. Cues for segmenting protocols included; pauses, changes of tone as well as the conclusion of sentences (Middleton, 2008).

As the verbal segments were inputted, the visual data were also monitored. This enabled a distinction to be made between sketching episodes and non-sketching episodes. Once all of the verbal data were inputted, Middleton’s (2008) categorisation of procedures was utilised to code the cognitive actions of each student. Each cognitive action was coded into one of ten procedures and was then located within one of three major categories of procedures as shown in Table 9.
Table 9 – Middleton’s categorisation of cognitive procedures

<table>
<thead>
<tr>
<th>Category of Procedure</th>
<th>Generation</th>
<th>Exploration</th>
<th>Executive Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td>Retrieval (R)</td>
<td>Exploring Constraints (EC)</td>
<td>Goal Setting (GSet)</td>
</tr>
<tr>
<td></td>
<td>Synthesis (S)</td>
<td>Exploring Attributes (EA)</td>
<td>Strategy Formulation (SF)</td>
</tr>
<tr>
<td></td>
<td>Transformation (T)</td>
<td></td>
<td>Goal Switching (GSwit)</td>
</tr>
</tbody>
</table>

The terms for each of the procedures are explained in Appendix 3. The researcher coded all the segments independently in order to maintain internal reliability throughout the study. Where there was uncertainty surrounding the coding of some verbal data, the visual data were examined to determine a better insight into the nature of the cognitive action.

Within visual and verbal protocol analysis it is important to divide the data into a number of parts to allow for in-depth analysis. Some researchers such as Suwa et al. (1998b), resort to breaking the segments down according to the number of pages of sketches produced. In contrast, Middleton (2008) cites the importance of pauses and changes in the rate of problem solving during sketching based design activities and they base the division of the verbal data on the duration of the entire sketching episode. This approach by Middleton (2008) was adapted in this study, where the entire twenty minute duration was broken down into ten, two minute tentiles. A tentile represented one tenth of the overall sketching period.

When all the pre and post instruction data were broken into tentiles, it enabled the creation of two graphs for each student which illustrated the amount of cognitive actions and their corresponding categories for both sketching episodes. An example of the type of graph is shown in Figure 44. These graphs provided a means of analysing students sketching behaviour and cognition during each sketching episode.
The sketches generated by each student at pre and post-instruction were also compared and analysed to determine their type, number and quality. Finally, further analyses of the verbal data in addition to the student’s qualitative comments during the model of sketching activities provided a means for a deeper level of analysis of student motivation, difficulties encountered and value systems.

4.5 Summary

The mixed methods Primary Research study enabled the collection and recording of data that provided a comprehensive insight into the development of student’s sketching ability. The data gathered included:

- Qualitative and quantitative data describing the students learning experiences which was gathered during the model of sketching activities.
- A ranked order of pre and post-instruction conceptual sketches which was generated using Comparative Pairs Assessment.
- Pre and post-instruction student self-ratings of sketching ability.
- Measures of different student cognitive factors which were gathered using pre and post-instruction psychometric tests.
- A comprehensive and rich source of data recorded using visual and verbal protocol analysis of a design based sketching task.

The findings from the study are presented in the next section.
5 FINDINGS
5.1 Overview

The research findings presented in this chapter are based on the Primary Research Study. The chapter is presented in three main sections and addresses the following research questions.

- **Is sketching a teachable skill?** Statistical data from the examination of student’s pre and post-instruction conceptual sketches through Comparative Pair’s assessment are presented in addition to student’s self-categorisation of sketching ability at pre and post-instruction.

- **How was sketching skill developed?** Qualitative and quantitative data which provides a detailed insight into the students learning experiences, performance and value placed in the model of activities are presented.

- **How effective is the model in developing sketching expertise?** The results of pre and post-instruction visual and verbal protocols, conceptual sketching tasks and psychometric tests are presented in order to gain an insight into students sketching behaviour and cognition at pre and post-instruction.
5.2 Is Sketching a Teachable Skill?

5.2.1 Student Self-Categorisation

The two methods applied to establish if the ability to sketch was a teachable skill were the self-categorisation of sketching ability and Comparative Pairs Assessment at pre and post-instruction. The first method involved asking students to rate their sketching ability at pre and post-instruction. Students were required to rate their ability along a five point Likert Scale.

A Wilcoxon Signed Rank Test of the pre and post-instruction ratings revealed a statistically significant increase in perceived sketching ability following participation in the model of sketching activities, $z = -7.322$, $r < 0.001$, with a large effect size ($r = 0.52$). The median score on the sketching ability rating scale increased from pre-instruction (Md = 2.00) to post-instruction (Md = 4.00). This suggests that students generally felt that they improved their ability to sketch. However, this measure was subjective in nature and it required another measure in order to validate it. This second measure was Comparative Pairs Assessment.

5.2.2 Comparative Pairs Assessment

A total of 242 pre and post-instruction conceptual sketches were assessed by 67 judges. 1,950 judgements were made resulting in a ranked order being produced where the 1st ranked sketch was judged to have been the best and the 242nd ranked sketch judged to have been the worst.
5.2.2.1 Reliability of the assessment

The ranked order generated by the Comparative Pairs Assessment software is illustrated in Figure 45. Note, this graph contains both pre and post instruction sketches. The sketch on the top right was considered the best and the sketch on the bottom left was considered the worst. For clarity purposes the rank order is separated into pre-instruction sketches and post-instruction sketches in Figure 46. This enables a clear distinction to be made between the two. The top of the rank generally contains post-instruction sketches while the bottom of the rank generally contains pre-instruction sketches. The statistical analysis data for the reliability of the assessment are presented in Table 10.

![Figure 45](image1.png)

Figure 45 – Ranked order generated by Comparative Pairs software

![Figure 46](image2.png)

Figure 46 – Generated ranked order of student sketches
Table 10 – Statistical data for the Comparative Pairs Assessment

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability coefficient</td>
<td>0.973</td>
</tr>
<tr>
<td>Misfit Criterion = Mean + 2(Std. Deviation)</td>
<td>1.10 + 2(0.128) = 1.356.</td>
</tr>
<tr>
<td></td>
<td>65 judges out of a total of 67 judges meet this criterion</td>
</tr>
<tr>
<td>Standard Deviation of Object Parameters</td>
<td>4.072</td>
</tr>
</tbody>
</table>

After each judgement was completed the assessors were required to justify their decision with a comment. A total of 1,603 comments were recorded, analysed and categorised. These findings are illustrated in Figure 47 where the most frequent criteria applied included creativity, use of shapes and quality of sketching.

![Figure 47 – Comments influencing judge’s decisions during Comparative Pairs Assessment](image)

5.2.2.2 Levels of Improvement

As previously mentioned, a total of 242 sketches were assessed and these consisted of 124 pre-instruction and 118 post-instruction student sketches. At the end of the
assessment process each pre and post-instruction sketch had a rank position (as shown in Figure 46). The details for the resultant ranks are presented in Table 11.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Highest Rank Position</th>
<th>Lowest Rank Position</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction Sketches</td>
<td>124</td>
<td>4</td>
<td>245</td>
<td>147.78</td>
<td>68.34</td>
</tr>
<tr>
<td>Post-Instruction Sketches</td>
<td>118</td>
<td>1</td>
<td>244</td>
<td>98.08</td>
<td>65.09</td>
</tr>
</tbody>
</table>

A Wilcoxon Signed Rank Test revealed a statistically significant decrease in rank position following participation in the model of sketching activities, \( z = -6.419, r < 0.001 \), with a medium effect size \( r = 0.43 \). The median score on the rank order decreased from pre-instruction (Md = 166.00) to post-instruction (Md = 88.00). Therefore, it was concluded that a significant number of student’s sketching ability improved as a result of participating in the model of sketching activities during the Primary Research Study. This also generally validates the self-categorisation of students sketching ability (Section 5.2.1). It should be noted that a decrease in rank position indicates improvement\(^\text{10}\).

Although 137 students participated in the research, the dynamic and large scale nature of the study made it difficult to ensure that every student completed a pre and post-instruction sketch. A total of 109 students completed both a pre and post-instruction sketch. Based on the results of the Comparative Pairs Assessment it was possible to calculate how many places each student improved or disimproved where \( \text{Rank Shift} = \text{Post-Instruction Rank} - \text{Pre-Instruction Rank} \). These results are illustrated in Figure 48 where the rank shift (y-axis) is compared with each student’s post-instruction rank position (x-axis). For example the student who ranked 1st with a

\(^{10}\text{For example; a pre-instruction rank of 30 and a post-instruction rank of 5 is a decrease in rank position.}\)
post-instruction sketch moved 223 places in the rank from their pre-instruction position.

![Figure 48 - Rank Shift compared with Post-Instruction Rank Position](image)

As described in Section 4.4.3.3, it was necessary to calculate the weighted shift for each student using two equations (2, 3). The resultant weighted shift score (y-axis) for each student compared to student’s post-instruction sketch rank position is illustrated in Figure 49.
The relationship between Weighted Shift and Post-Instruction Rank was investigated using Spearman rho. There was a strong, negative correlation between the two variables, \( r = -0.780, n = 109, r < 0.0005 \), with high levels of weighted shift associated with low post-instruction rank position.

The entire group of 109 students was divided into two groups: “Positive Movers” and “Negative Movers”. This categorisation of students facilitated the analysis of qualitative and quantitative data which are described in the next section. The relationship between weighted shift and rank order shift is illustrated in Figure 50 where the x-axis represents student numbers. From the graph it is evident that there was a slightly uneven distribution of rank shift. However, the weighted shift normalises these data. This enabled a comparison to be drawn between the different types of movers. The pre and post-instruction rank positions and weighted shift scores for all students are presented in Appendix 8 (Volume 2).
Examples of the type of sketches produced by a “Highly Positive Mover” and a “Negative Mover” are presented in Figure 50 and Figure 51. On initial visual examination, the development of sketching skill in Student 31 (Figure 51) and lack of development in Student 89 (Figure 52) is evident. The next section examines the student’s self-ratings of their own sketches and the value they placed in their learning experiences in order to establish the effectiveness of the model of sketching activities.
Student 31 - Group 1
(Highly Positive Movers)

Pre-Instruction Sketch  Post-Instruction Sketch

Figure 51 - Example of a Highly Positive Mover

Student 89 - Group 4
(Negative Movers)

Pre-Instruction Sketch  Post-Instruction Sketch

Figure 52 - Example of a Negative Mover
5.3 How was sketching skill developed?

This section of the findings presents the gathered data which describe the effectiveness of the model of activities (Figure 53) and its impact on student performance.

At the end of each activity, the students were required to rate their sketches, rate the value of the activity and provide any feedback through comments. The students’ sketches were also assessed by the researcher. The findings for the entire cohort of students are presented in Figure 54. A selection of students’ sketches completed during the model of activities is presented in Appendix 4 while all students’ sketches are presented in Appendix 26-28 (Volume 2).
A broad overview of these statistics highlights that the students mean ratings were generally lower than the researcher scores. In addition to this, the mean value that the students placed in the activities was generally higher in the initial activities. In order to gain a deeper insight into this data the “Positive Movers” and “Negative Movers” were treated separately. The following section presents each group’s mean score for their self-rating of sketches, value they placed in each activity and the researcher scores. Within each graph the dashed lines are derived from Figure 53 and represent the transition from observational type drawing towards conceptual imaginative sketching.

All comments provided by the students at the end of each activity in addition to pre and post-instruction comments are presented in Appendix 9 – 25 (Volume 2) where they are coded and graphed.
5.3.1 Student Self-Rating Scores

The mean self-rating scores for both “positive movers” and “negative movers” are illustrated graphically in Figure 55. Interestingly, the “negative movers” generally outperformed the “positive movers” throughout the model of activities. This would suggest a number of things including that the “positive movers” may have been more self-reflective and critical of their sketches or that the “negative movers” generally tended to be better sketchers.

![Student Self-Ratings](image.png)

Figure 55 – Student self-ratings

A Mann-Whitney U Test was carried out to determine if there were any significant differences between the two groups in self-rating scores for each activity. The tests revealed a significant difference with small effect size in self-ratings for Auxiliary Journey with “negative movers” (Md = 7.00, n = 18) and “positive movers” (Md = 6.00, n = 82), U = 446.00, z = -2.678, p = 0.007, r = 0.27. No other significant differences were observed.
5.3.2 Researcher assessment of student sketches

Each of the students' sketches which were completed during the model of activities were examined and scored out of ten by the researcher. Criteria such as quality of sketching and creativity were applied. This was done at the end of each activity and the researcher was not able to identify the students name when assessing the sketches. All of these sketches are presented in Appendix 26 (Volume 2). Note, the Journey (a) and Journey (b) activities were not assigned grades as these were group activities. The results for both “Positive Movers” and “Negative Movers” are illustrated in Figure 56. It was notable that the “Negative Movers” consistently scored higher in all tasks until they reached the “Transfer” activity stage. The performance scores become very mixed after this observational drawing stage suggesting a possible change in student’s application, motivation and their value in the activities.

![Researcher Scores](image)

Figure 56 – Researcher assessment of student sketches

A Mann-Whitney U Test was carried out to determine if there were any significant differences between the two groups for the researcher scored sketches. The tests
revealed a significant difference with small effect size in scores for Auxiliary Journey with “negative movers” (Md = 7.00, n = 19) and “positive movers” (Md = 7.00, n = 84), U = 492.00, z = -2.955, p = 0.003, r = 0.29. No other significant differences were observed.

5.3.3 Student value in activities

Subsequent to completing each activity the students were asked to rate the value that they placed in the activity along a ten point scale. These results are illustrated in Figure 57. The “Negative Movers” generally placed more value in the activities between “Recognition” and “Transfer” which were mainly observational drawing based. Subsequent to “Transfer” there was a significant shift in the trend as the “Positive Movers” generally placed more value in the latter activities which were focused on sketching from memory and imagination.

A Mann-Whitney U Test was carried out to determine if there were any significant differences between the two groups in the value placed in each activity. The tests
revealed a significant difference with small effect size in value scores for Journey (a) with “positive movers” (Md = 7.00, n = 81) and “negative movers” (Md = 7.00, n = 20), U = 581.50, z = -1.984, p = 0.047, r = 0.20. No other significant differences were observed.

This general trend where the “Positive Movers” generally valued the activities subsequent to “Transfer” higher than the “Negative Movers” was also evident in the comments of a range of students from either group in Table 12. It was felt that the selected comments were representative of the groups. It is notable that the “Positive Movers” were generally very positive about the activities throughout even though they found several elements to be difficult. On the other hand, the “Negative Movers” generally found the initial tasks easy and interesting. However, once these students reached the “Enlightenment” activity their comments started to become mixed with some evidence of loss of interest and motivation.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Student Comment</th>
<th>Student Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>I found it hard to sketch the drawing without boxes, the box helped to locate the lines and I found this very helpful – <strong>Student 124 (Significantly Positive Mover)</strong></td>
<td>I found it very interesting. When focusing on one section made it easier than if it was one big picture – <strong>Student 56 (Negative Mover)</strong></td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>Really enjoyed both activities. Nice change to standard measured drawings – <strong>Student 125 (Significantly Positive Mover)</strong></td>
<td>I enjoyed this drawing as using the pencil to measure was a great method of measurement – <strong>Student 131 (Negative Mover)</strong></td>
</tr>
<tr>
<td>Enquiry</td>
<td>Really tested my sketching ability. Highlighted problem areas. Eye opener of an exercise - <strong>Student 125 (Medium Positive Mover)</strong></td>
<td>Think the exercise was a bit big – took too much to fill the page. It resulted in me just slopping colour on the page - <strong>Student 131 (Negative Mover)</strong></td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>I felt that with the amount of sketching that we have done that my sketching in this exercise was much better quality but also a lot faster and smoother - <strong>Student 129 (Significantly Positive Mover)</strong></td>
<td>My sketching is improving. By using the picture plane, I was able to sketch more accurately - <strong>Student 120 (Negative Mover)</strong></td>
</tr>
<tr>
<td>Transfer</td>
<td>Not enough time to do it right and accurately. Casting the shadow though was very hard to do - <strong>Student 104 (Significantly Positive Mover)</strong></td>
<td>Difficult to complete the task in the given time but probably worked better because I was under pressure - <strong>Student 115 (Negative Mover)</strong></td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>It gets you thinking and rotating the object in your mind. Looking at different views and putting them on paper as they would look - <strong>Student 132 (Significantly Positive Mover)</strong></td>
<td>My drawings were messy. It is harder than I thought to draw a simple pin. Shading and positioning was also hard - <strong>Student 51 (Negative Mover)</strong></td>
</tr>
</tbody>
</table>

123
<table>
<thead>
<tr>
<th>Activity</th>
<th>Feedback</th>
<th>Additional Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlightenment</td>
<td>Good exercise. I got better as it went on. Helps you to remember things better - <strong>Student 102</strong> (Significantly Positive Mover)</td>
<td>I thought this activity was more of a memory test than a sketching exercise. The reason I gave it a four was because it was mainly like the leaving certificate trying to remember and regurgitate and sketching was only second fiddle - <strong>Student 131</strong> (Negative Mover)</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>This was the largest time we ever put into any sketch but as I spent more and more time at it I was able to see the different textures and hatching that was needed - <strong>Student 132</strong> (Significantly Positive Mover)</td>
<td>Challenging but very engaging and interesting. Optional extra workshops would be a great help - <strong>Student 123</strong> (Negative Mover)</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>I feel that it brings out pupils creative side and it allows people to use their imagination a lot more and express themselves - <strong>Student 10</strong> (Significantly Positive Mover)</td>
<td>There was more time wasted thinking of what to do than on what we actually drew - <strong>Student 108</strong> (Negative Mover)</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Good way to be constantly changing perspective and advancing ideas - <strong>Student 122</strong> (Significantly Positive Mover)</td>
<td>I found building on other people’s ideas much easier than having to create one for yourself - <strong>Student 53</strong> (Negative Mover)</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>This is a good exercise as it allows you to think of using geometries in other ways - <strong>Student 21</strong> (Medium Positive Mover)</td>
<td>Didn’t really learn anything new by doing this exercise. Difficult to think of ideas in a short space of time - <strong>Student 120</strong> (Negative Mover)</td>
</tr>
<tr>
<td>General Feedback</td>
<td>I enjoyed it but I could do with more feedback on how to improve - <strong>Student 124</strong> (Significantly Positive Mover)</td>
<td>Sketching the interpenetration question I found awkward as them questions are tough enough to draw and sketching them was messy and quite hard to read when finished – <strong>Student 56</strong> (Negative Mover)</td>
</tr>
</tbody>
</table>
So far the findings presented in this chapter have described the results of a number of measures. These are summarised as follows:

- A large majority of the students rated their sketching ability as being better subsequent to completing the model of activities.
- Based on the results of the Comparative Pairs Assessment of the pre and post-instruction conceptual sketching tasks it was found that the students performed significantly better at post-instruction. This finding is significant as it validates the model of activities in developing sketching ability.
- It was found that the transitional shift from observational drawing to conceptual sketching had a significant effect on both “Positive Movers” and “Negative Movers”. The “Positive Movers” tended to embrace the shift in cognitive focus while the “Negative Movers” were less positive. This was particularly evident in the value that students placed in the activities and was generally supported in the students’ qualitative comments (Table 12).

At this stage it was clear that the model of sketching activities was very effective in developing student’s ability to freehand sketch. The findings suggest that the shift in cognitive focus from observational drawing through to memory and conceptual sketching was critical. The importance of building on observational drawing skills to effectively retrieve, manipulate and synthesise “geometric libraries” (Storer, 2008) during “sense-making” (Jonson, 2005) conceptual activities became very clear. It was found that the “Positive Movers” generally placed more value in the memory and imaginative activities (Figure 57). Their qualitative comments (Table 12) and the researcher scores (Figure 56) also indicate that this shift was a critical point in the students’ development.

In order to further examine what effect this change in cognitive focus had it was necessary to consider the results of the psychometric tests and visual and verbal protocol analysis. These are presented in the next section.
5.4 How effective is the model in developing sketching expertise?

This section of the chapter presents the findings of the pre and post-instruction psychometric measures and the visual and verbal protocols. The analysis of data gathered from these two methods was critical in determining the effect which participating in the model of sketching activities had on student’s cognition and sketching behaviour.

5.4.1 Psychometric Tests

Four psychometric tests were administered at both pre and post-instruction stages. These included a “Storage Test”, “Figural Classification Test”, “Letters Test” and “Locations Test” (Ekstrom et al., 1976). The tests measured cognitive factors of “Figural Flexibility” and “Induction”. The literature relating to expertise in freehand sketching suggests that expert sketchers perform better in these types of tests (Verstijnen, 1998b, Kavakli et al., 1999).

A Wilcoxon Signed Rank Test was carried out to establish if there was any difference in psychometric test scores between pre and post-instruction. A statistically significant increase in “Storage Test” scores was observed following participation in the model of sketching activities, \( z = -5.283, r < 0.001, \) with a medium effect size \( (r = 0.39) \). The median score on the Storage Test scale increased from pre-instruction \( (Md = 14.50) \) to post-instruction \( (Md = 17.00) \). No other significant differences were observed. This significant difference between Storage Test scores was also observed during Preliminary Study 3.

A Mann-Whitney \( U \) Test was conducted to explore the impact of student groupings (“Positive Movers” and “Negative Movers”) for both pre-instruction and post-
instruction psychometric tests scores. No significant differences were observed. Descriptive statistics for the psychometric tests are presented in Table 13.

<table>
<thead>
<tr>
<th>Test</th>
<th>Group</th>
<th>Pre-Instruction Mean</th>
<th>Pre-Instruction Std. Deviation</th>
<th>Post-Instruction Mean</th>
<th>Post-Instruction Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Test</td>
<td>Positive Movers</td>
<td>14.44</td>
<td>4.56</td>
<td>17.16</td>
<td>6.01</td>
</tr>
<tr>
<td></td>
<td>Negative Movers</td>
<td>15.16</td>
<td>6.01</td>
<td>18.05</td>
<td>6.11</td>
</tr>
<tr>
<td>Figural Classification Test</td>
<td>Positive Movers</td>
<td>110.83</td>
<td>46.50</td>
<td>105.22</td>
<td>56.19</td>
</tr>
<tr>
<td></td>
<td>Negative Movers</td>
<td>113.92</td>
<td>57.52</td>
<td>114.52</td>
<td>58.36</td>
</tr>
<tr>
<td>Locations Test</td>
<td>Positive Movers</td>
<td>9.96</td>
<td>5.55</td>
<td>10.16</td>
<td>6.58</td>
</tr>
<tr>
<td></td>
<td>Negative Movers</td>
<td>10.60</td>
<td>6.71</td>
<td>6.6</td>
<td>5.48</td>
</tr>
<tr>
<td>Letters Test</td>
<td>Positive Movers</td>
<td>13.34</td>
<td>7.16</td>
<td>12.48</td>
<td>7.74</td>
</tr>
<tr>
<td></td>
<td>Negative Movers</td>
<td>15.21</td>
<td>6.00</td>
<td>12.45</td>
<td>7.55</td>
</tr>
</tbody>
</table>

As the statistical analyses did not yield any significant results, it was not necessary to explore them further. The findings from the Visual and Verbal Protocol Analysis are presented in the next section.

### 5.4.2 Visual and Verbal Protocol Analysis

41 students participated in the visual and verbal protocol analysis. Rather than analysing every student’s data it was decided to select eleven students across both groups of movers. The students who were considered for selection must have had completed both episodes of visual and verbal protocols. Once all these students were identified, eleven students were evenly selected across the broad range of
weighted scores. The weighted scores and rank shifts for the selected students are highlighted in Figure 58.

![Weighted Shift versus Rank Shift](image)

Figure 58 – Selected Students for Visual and Verbal Protocols Analysis

Research literature (Kavakli et al., 1999) concerning expertise in freehand sketching suggests that experts generally tend to exhibit a higher number of cognitive actions than novices during design based sketching tasks. The visual and verbal data for all eleven students was analysed and coded. The total number of cognitive actions at pre and post-instruction for each student is shown in Figure 59.
A Wilcoxon Signed Rank Test was carried out to establish if there was any significant difference in the number of cognitive actions between pre and post-instruction. No significant differences were observed. Therefore it was concluded that some other change in sketching behaviour may have occurred. Examples of possible changes included different types of cognitive actions evidenced or different types of sketches being generated.

Further analysis of the visual and verbal data (for the selected 11 students) enabled the categorisation of each cognitive action for every student into a category of procedure. These data are presented in Figure 60.
A Wilcoxon Signed Rank Test was carried out to establish if there was any significant difference in the number of each type of procedure between pre and post-instruction. Significant differences were found for both “Synthesis” and “Exploring Constraints” type actions with large effect size. These statistics are presented in Table 14. The increase in both “Synthesis” and “Exploring Constraints” procedures is in line with literature (Kavakli et al., 1999) relating to expertise in freehand sketching where expert sketchers tend to formulate and generate more proposals to solve problems than novices.

Table 14 – Significant Differences in number of cognitive actions

<table>
<thead>
<tr>
<th></th>
<th>N (cases x 2)</th>
<th>z</th>
<th>Sig.</th>
<th>Effect Size (r)</th>
<th>Pre-Instruction (Md)</th>
<th>Post-Instruction (Md)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis</td>
<td>22</td>
<td>-2.758</td>
<td>0.006</td>
<td>0.58</td>
<td>45.00</td>
<td>67.00</td>
</tr>
<tr>
<td>Exploring Constraints</td>
<td>22</td>
<td>-2.520</td>
<td>0.012</td>
<td>0.54</td>
<td>1.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>
5.4.3 Analysis of Individual Students

It is important to note at this stage that no significant differences between groups were observed in terms of Psychometric measures or the type and number of cognitive procedures evidenced in each sketching episode. In order to further comprehend the sketching behaviour of the students at pre and post-instruction, a plot of their cognitive actions was generated for both pre and post-instruction sketching episodes. These plots were based on Middleton’s (2008) categorisation of cognitive procedures of actions and the subsequent categorisation of these procedures into categories of Executive Control, Generation and Exploration (Figure 61).

The next section presents a commentary for every student which synthesises the pre and post-instruction visual and verbal protocols data, each student’s pre and post-instruction conceptual sketches in addition to the qualitative feedback. Through this level of analysis it was envisaged that a clearer picture of each student’s development could be determined in addition to providing indications why the majority of students were “Positive Movers” and a minority of students were “Negative Movers”.

![Middleton (2008) Expert Graph](image-url)
5.4.3.1 Commentary for Student 86

Student 86 rated his pre-instruction sketching ability as “Poor” and post-instruction as “Good”. He was classified as a “significant positive mover” based on a weighted shift of 267 with pre-instruction rank of 114 and post-instruction rank of 3.

Analysis of the pre and post-instruction conceptual task sketches (Figure 62) for Student 86 indicated that his sketching ability was quite sophisticated prior to instruction despite his self-rated “Poor” categorisation. The pre-instruction sketch pictorially depicted a robot type character in motion. The post-instruction displayed a similar quality of sketching with a noticeable improvement in creativity with some humour and the generation of two sketches.

![Student 86 Pre-Instruction Sketch](image1)
![Student 86 Post-Instruction Sketch](image2)

Figure 62 – Pre and Post Instruction Conceptual Task Sketches for Student 86

The pre and post-instruction cognitive data (Figure 63 and Figure 64) for the visual and verbal protocol analysis did not reveal any significant differences. It was notable however that Student 86 engaged in high levels of exploration at the start of both activities and his generation actions gradually increased as he progressed through the tasks. This is comparable to the behaviour of Middleton’s expert (Figure 61).
Figure 63 – Plots of Cognitive Actions for Student 86
Figure 64 – Breakdown of plots for Student 86
The pre-instruction visual and verbal protocol sketches (Figure 65) produced by Student 86 depicted an apparatus for boiling water that the student designed for his father who was from a farming background with particular emphasis on saving hay. The post-instruction visual and verbal protocol sketches (Figure 66) depicted the design of a toy for the student’s next door neighbour who was one and half years old. It was interesting that there was a higher level of sophistication and detail in the sketches produced at post-instruction with a number of pictorial sketches evidenced. In contrast, the type of sketches that were produced at pre-instruction was two-dimensional with significantly less detail communicated. However, it was noteworthy that both sketching episodes involved the creation of conceptually derived solutions.

![Figure 65 – Pre Instruction Visual and Verbal Protocols Sketches for Student 86]
Throughout the model of activities Student 86 was consistently positive about his learning experiences and his comments (Table 15) were very much centralised around seeking improvement and identifying areas that he wished to develop and work on. This intrinsic motivation to improve and the value that he placed in the activities provide significant evidence as to why this student improved so significantly.

Table 15 – Selection of Comments for Student 86

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary</td>
<td>I thought this exercise provided me with the scaffolding to complete an accurate sketch of the running man. I feel as it was a freehand sketch exercise that tested my sketching ability. It will develop my sketching ability.</td>
</tr>
<tr>
<td>Recognition</td>
<td></td>
</tr>
<tr>
<td>Auxiliary</td>
<td>Found the exercise time consuming as I spent some time on some of the sketches</td>
</tr>
<tr>
<td>Enquiry</td>
<td></td>
</tr>
<tr>
<td>Transfer</td>
<td>Challenging, enjoyable and effective</td>
</tr>
<tr>
<td>Auxiliary</td>
<td></td>
</tr>
<tr>
<td>Transfer</td>
<td>It challenged me to constantly imagine the object as a 3D object. Provided me with a chance to manipulate different viewing angles.</td>
</tr>
</tbody>
</table>
5.4.3.2 Commentary for Student 125

Student 125 rated his pre-instruction sketching ability as “Not Sure” and post-instruction ability as “Good”. He was classified as a “significant positive mover” based on a weighted shift of 214 with pre-instruction rank of 155 and post-instruction rank of 34.

A number of observations were made on analysis of the pre and post-instruction conceptual task sketches for Student 125 (Figure 67). The pre-instruction sketch contained both annotations and a pictorial representation of a character which could be considered unsophisticated and not very creative. Interestingly, there was a resemblance of this same character in the post-instruction sketch. However, it was evident that a degree of exploration took place with the subsequent generation of another conceptual character which was more complex in nature albeit with a limited creativity.

The pre and post-instruction cognitive data (Figure 68 and Figure 69) for the visual and verbal protocol analysis revealed a general increase in cognitive actions across all three categories. This aligns with literature in freehand sketching where Kavakli et al. (1999) found that expert sketchers display a higher number of cognitive actions during design based sketching tasks. The Generation and Exploration actions evidenced at post-instruction were very similar with Middleton’s (2008) expert.
Figure 68 - Plots of cognitive actions for Student 125
Figure 69 – Breakdown of plots for Student 125
The pre-instruction visual and verbal protocol sketches (Figure 70) produced by Student 125 depicted an artefact for boiling water which the student designed for inter-county GAA\textsuperscript{11} players. The post-instruction visual and verbal protocol sketches (Figure 71) depicted the design of a toy for the student’s seven year old cousin who enjoyed farm machinery. Interestingly, Student 125 tended to approach both tasks using a mixture of both sketches and annotations. There was a remarkable difference in the type of sketches produced between pre and post-instruction. The pre-instruction sketch was completely flat and two-dimensional while the post-instruction sketch was much more sophisticated, detailed and was represented pictorially.

\textbf{Figure 70} – Pre Instruction Visual and Verbal Protocols Sketches for Student 125

\textsuperscript{11} GAA are players are people who participate in native Irish sports which include Hurling and Gaelic Football
Similar to Student 86, Student 125 was consistently positive about his learning experiences. His comments (Table 16) very much underline the enjoyment and value that he had in the activities in addition to highlighting the areas that he felt he needed to improve. This intrinsic motivation to improve and the value that he placed in the activities provide significant evidence as to why this student improved so significantly.

Table 16 – Selection of Comments for Student 125

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-instruction visual and verbal protocols</td>
<td>When I first got the activity I was kind of taken back by the fact that I had to design a kettle. The short notice was a challenge. Good experience trying to think of something on the think of. I chose the hurler because of my interests. I really enjoyed the activity.</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>Really enjoyed both activities. Nice change to standard measured drawings</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>Enjoyed exercise. Improved on sketching real items to paper by the end of the task</td>
</tr>
<tr>
<td>Transfer</td>
<td>Enjoying the sketching part of this module as I find myself progressing in my ability to sketch</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>Different exercise to the other ones. Got me thinking a lot more than sketching exercises previous to this. Had to concentrate more in order to find new angles and new points of viewing at the pin. Enjoyed the activity</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>Felt I didn’t perform and couldn’t seem to think of any way of incorporating the shapes. I felt it was a good activity but my visualisation was very poor on this activity</td>
</tr>
</tbody>
</table>
5.4.3.3 Commentary for Student 104

Student 104 rated his pre-instruction sketching ability as “Not Sure” and post-instruction ability as “Good”. He was classified as a “significant positive mover” based on a weighted shift of 203 with pre-instruction rank of 112 and post-instruction rank of 29.

There were significant differences between the pre and post-instruction conceptual sketches produced by Student 104 (Figure 72). The pre-instruction sketch was a flat, two-dimensional single representation of the basic geometries where the spheres were represented as circles and the rectangular prism as basic rectangles. On the other hand, the post-instruction sketch contained several depictions, evidence of exploration and a very sophisticated and detailed pictorial representation of a character who appeared to be roller skating.

![Student 104 Pre-Instruction Sketch](image1.png) ![Student 104 Post-Instruction Sketch](image2.png)

Figure 72 - Pre and Post Instruction Conceptual Task Sketches for Student 104

The pre and post-instruction cognitive data (Figure 73 and Figure 74) for the visual and verbal protocol analysis revealed remarkably similar pre and post-instruction levels of Generation similar to Middleton’s (2008) expert. Executive Control actions decreased at post-instruction while Exploration actions increased.
Figure 73 – Plots of cognitive actions for Student 104
Figure 74 – Breakdown of plots for Student 104
The pre-instruction visual and verbal protocol sketches (Figure 75) produced by Student 104 depicted an artefact for boiling water which the student designed for his father with a hurling theme. The post-instruction visual and verbal protocol sketches (Figure 76) initially depicted the design of a storage unit for hurleys for the student’s young cousin but subsequent to reflecting on their initial idea the focus changed to the design of a toy tractor. There were a higher number of sketches produced at post-instruction and this could be due to the higher levels of exploration and idea generation. The quality of sketching at post-instruction was of a slightly better standard with more detailed sketches and a higher number of more complex pictorial representations.

Figure 75 – Pre Instruction Visual and Verbal Protocols Sketches for Student 104
The qualitative comments (Table 17) provided very interesting evidence as to how Student 104 embraced the model of activities and their subsequent improvement. The comments indicate that this student was constantly critiquing himself about what he needed to improve upon suggesting high levels of intrinsic motivation. Comments relating to time being “too short” indicate that the student had a high value in their sketches and were really interested in improving. Interestingly when the activities progressed towards conceptual type sketching at “Journey (a)” and “Journey (b)” the student found them both interesting and fun while the anxiety which was evident in previous activities had dissipated.

Table 17 – Selection of Comments for Student 104

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enquiry</td>
<td>Again performing is tricky and also proportion size is hard to get</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>Again this activity has given me more confidence in sketching and my sketches are getting noticeably better as I progress in this module. Very beneficial exercise</td>
</tr>
<tr>
<td>Transfer</td>
<td>Not enough time to do it right and accurately. Casting the shadow though was very hard to do</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>Time was short, so things were a bit rushed. Hard to draw the shadows all the time. Hard to get the pin the perfect shape all the time</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>Overall shaping was easy enough but getting the colours to the perfect shade was difficult</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>More time was needed but good activity. Interesting and fun to do</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Fun exercise and it was interesting to find out how your drawing turned out</td>
</tr>
</tbody>
</table>
5.4.3.4 Commentary for Student 134

Student 134 rated his pre-instruction sketching ability as "Not Sure" and post-instruction ability as "Good". He was classified as a "medium positive mover" based on a weighted shift of 185 with pre-instruction rank of 182 and post-instruction rank of 59.

Analysis of the pre and post-instruction conceptual sketches (Figure 77) produced by Student 134 revealed some interesting points. There was a similar level of exploration evident in the sketches for both tasks. On both occasions Student 134 attempted to represent using pictorial depictions. There was a noticeable increase in creative expression in the post-instruction task where the student used a theme relating to a character lifting the different geometries. There was also an attempt made to render the post-instruction sketches while this was not evident at pre-instruction.

![Student 134 Pre-Instruction Sketch](image1)

![Student 134 Post-Instruction Sketch](image2)

Figure 77 – Pre and Post Instruction Conceptual Task Sketches for Student 134

The pre and post-instruction cognitive data (Figure 78 and Figure 79) for the visual and verbal protocol analysis revealed an increase in both Generation and Exploration actions at post-instruction which were very similar to Middleton’s (2008) expert.
Figure 78 - Plots of cognitive actions for Student 134
Figure 79 – Breakdown of cognitive actions for Student 134
The pre-instruction visual and verbal protocol sketches (Figure 80) produced by Student 134 depicted an artefact for boiling water that the student designed for his sister who earlier that week scalded herself while making a cup of tea. The post-instruction visual and verbal protocol sketches (Figure 81) depicted the design of a GAA themed quiz game which the student designed for his younger brother who enjoyed hurling. There were a higher number of sketches produced at pre-instruction but these were predominantly two-dimensional in nature with limited detail. In contrast, the post-instruction sketches produced were almost entirely pictorially represented with significant detail communicated.

![Pre Instruction Visual and Verbal Protocols Sketches for Student 134](image)

Figure 80 – Pre Instruction Visual and Verbal Protocols Sketches for Student 134
The qualitative comments (Table 18) provided by Student 134 suggested that they really valued the educational significance of improving sketching ability through the model. It was notable that the student generally found the activities to be very beneficial and that sketching could “be improved with practice”. The student did express difficulty in generating conceptual ideas during “Journey (a)” and conceded that their sketches “wouldn’t be brilliant” which suggested the student was self-reflective and constantly critiquing himself.

Table 18 – Selection of Comments for Student 134

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary</td>
<td>Good for being able to visualise different stuff in graphics education</td>
</tr>
<tr>
<td>Recognition</td>
<td></td>
</tr>
<tr>
<td>Enquiry</td>
<td>I found this good as it is practical sketching, visualising and also adding colour and shading</td>
</tr>
<tr>
<td>Auxiliary</td>
<td>Yes I thought it was a good exercise as it challenged us to sketch everyday objects. I didn’t find the small picture plane of much benefit as it was hard to hold steady</td>
</tr>
<tr>
<td>Enquiry</td>
<td></td>
</tr>
<tr>
<td>Auxiliary</td>
<td>I found that this activity improved my ability to sketch the pin; it showed me that sketching can be improved with practice. I don’t really have any set style though like I would wonder how I would teach it to young children; I suppose it’s all about confidence. I found that in this activity, I took more of a re-structuring approach to this sketching activity and found it better than doing sketches where I was trying to make them perfect in the first draft.</td>
</tr>
<tr>
<td>Transfer</td>
<td></td>
</tr>
<tr>
<td>Journey (a)</td>
<td>Was a bit of fun, hard to think of things on the spot alright, you would be thinking “what the hell am I doing” half way through it. The sketches wouldn’t be unreal</td>
</tr>
</tbody>
</table>
5.4.3.5 Commentary for Student 42

Student 42 rated his pre-instruction sketching ability as “Not Sure” and post-instruction ability as “Good”. He was classified as a “medium positive mover” based on a weighted shift of 149 with pre-instruction rank of 160 and post-instruction rank of 73.

On initial examination, both the pre and post-instruction conceptual sketches (Figure 82) produced by Student 42 appeared somewhat similar. Both were depicting a character which was drawn in the same position with a sphere representing the head, a cone for the neck and cylinder for the trunk of the body. However, there appeared to be better functionality in the post-instruction sketch with the application of roller skates for movement in addition to an increased number of representations of the square based pyramid. There was also evidence of an attempt made to render the post-instruction sketch while this was not done at pre-instruction.

The pre and post-instruction cognitive data (Figure 83 and Figure 84) for the visual and verbal protocol analysis found that there was a decrease in the total number of cognitive actions. The trend lines for each category generally appeared similar although there was a higher degree of Exploration evident in the post-instruction sketching episode and a notable decrease in Executive Control actions at tentile 3 at post-instruction.
Figure 83 - Cognitive plots for Student 42
Figure 84 – Breakdown of cognitive actions for Student 42
The pre-instruction visual and verbal protocol sketches (Figure 85) produced by Student 42 depicted an artefact for boiling water which the student designed for his father who was a lorry driver. The post-instruction visual and verbal protocol sketches (Figure 86) depicted the design of tractor for the student’s four year old cousin who liked machinery. A similar number of sketches were produced at pre and post-instruction. During both sketching episodes the student produced very detailed and sophisticated sketches. It was obvious from the pre-instruction sketch that the student sketched a kettle largely from memory and this is supported in his comments where he stated that “actually it just looks like a normal kettle so I haven’t really met the brief”. The same could be claimed for the post-instruction sketch of the tractor which was probably drawn mostly from memory although the student did state on a couple of occasions that he was customising parts for his young cousin.

Figure 85 – Pre Instruction Visual and Verbal Protocols Sketches for Student 42
The number and type of qualitative comments (Table 19) provided by Student 42 are of particular interest. Student 42 didn’t provide any comment until he reached “Auxiliary Enquiry” when he stated that he found it difficult to use the small picture plane. Perhaps he found the previous activities easy as his sketching ability appeared to be good based on his performance in the pre-instruction visual and verbal protocols. He didn’t provide any more comments until he reached the conceptual type “Journey” activities where he stated that he found it difficult to think conceptually and he was also critical of “Journey (b)” activity which he said should be totally modified.

Table 19 – Selection of Comments for Student 42

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Enquiry</td>
<td>Found it difficult to use the picture plane</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>A lot more free</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Change completely</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>Not enough time. Found it hard to think/draw</td>
</tr>
</tbody>
</table>
5.4.3.6 Commentary for Student 96

Student 96 rated his pre-instruction sketching ability as “Poor” and post-instruction ability as “Good”. He was classified as a “medium positive mover” based on a weighted shift of 142 with pre-instruction rank of 216 and post-instruction rank of 104.

Analysis of both the pre and post-instruction conceptual sketches (Figure 87) produced by Student 96 provides some interesting observations. Although the pre-instruction sketch was presented pictorially, it lacked creativity and the student struggled to represent the geometries accurately. The post-instruction sketch was more creative however and the student represented one of his interests which were horse racing. Even though the representation of the horses was not very accurate, the student made a good attempt to synthesise the geometries.

The pre and post-instruction cognitive data (Figure 88 and Figure 89) for the visual and verbal protocol analysis show a decrease in the total number of cognitive actions at post-instruction. There was a notable change in sketching behaviour at post-instruction where the student started out with a high number of Exploration actions which gradually reduced and the Generation actions started with at low frequency and gradually increased. This was similar to Middleton’s expert (Figure 61).
Figure 88 – Plots of cognitive actions for Student 96
Figure 89 – Breakdown of cognitive actions for Student 96
The pre-instruction visual and verbal protocol sketches (Figure 90) produced by Student 96 depicted a scene drawn entirely from memory of the student’s grandfather’s house which had an open fireplace from where he used to boil water. In complete contrast, the post-instruction visual and verbal protocol sketches (Figure 91) depicted the design of different toys for the student’s seven year old neighbour who enjoyed farming and the outdoors but tended to wander and go missing from his parents. As the pre-instruction task (Figure 90) was a scene drawn entirely from memory it was broken down into three different sketches. It was drawn entirely in two-dimensional format. There were a total of thirteen post-instruction sketches (Figure 91) which were conceptual in nature and contained some detailed pictorial representations, most notably a pictorial sketch of a toy digger for the child.
The qualitative comments (Table 20) provided by Student 96 indicated that he really enjoyed and valued the learning experience although he did find it difficult to think conceptually when he reached the “Auxiliary Transfer” stage. This could be expected considering his memory based representations which he produced during the pre-instruction visual and verbal protocols. However, his comments do suggest that he began to feel comfortable sketching conceptually and that he really enjoyed the “Journey” activities. His comment after “Auxiliary Enlightenment” where he stated that it was unfortunate that the sketching activities were due to finish the following week provided evidence of the value he placed in the activities and his motivation to improve further.

Table 20 – Selection of Comments for Student 96

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enquiry</td>
<td>I would like to spend more time on this topic</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>I found it very hard to use the small picture plane in this activity. I feel if I had a bigger picture plane that we used in the lab that I would have found it easier.</td>
</tr>
<tr>
<td>Transfer</td>
<td>I found the transfer task much easier than the shadow and shade task</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>I found it difficult to draw the same object in so many orientations. I found that I was looking to my neighbours drawing to see different ways they did it.</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>I am enjoying this activity and I am improving. Pity it’s all stopping next week</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>I really enjoyed this.</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Improved my ability to think outside the box</td>
</tr>
</tbody>
</table>
5.4.3.7 Commentary for Student 92

Student 92 rated his pre-instruction sketching ability as “Poor” and post-instruction ability as “Good”. He was classified as a “low positive mover” based on a weighted shift of 100 with pre-instruction rank of 212 and post-instruction rank of 135.

Initial analysis of both the pre and post-instruction conceptual sketches (Figure 92) produced by Student 92 did not suggest any significant improvement in sketching quality. Both pre and post-instruction sketches lacked creativity and were basic in nature although there was an attempt on both occasions to sketch pictorially. A sole significant difference between pre and post instruction was an increased number of sketches which suggested increased levels of exploration and synthesis.

![Student 92 Pre-Instruction Sketch](image1)

![Student 92 Post-Instruction Sketch](image2)

Figure 92 – Pre and Post Instruction Conceptual Task Sketches for Student 92

The pre and post-instruction cognitive data (Figure 93 and Figure 94) for the visual and verbal protocol analysis revealed a remarkable increase in Generation actions at post-instruction which were almost identical to Middleton’s (2008) expert. Although the Exploration actions were less at post-instruction, the higher number of these actions at the start of the task closely mirror Middleton’s expert (Figure 61). No notable change was evident in Executive Control actions.
Figure 93 – Plots of cognitive actions for Student 92
Figure 94 – Breakdown of cognitive actions for Student 92
The pre-instruction visual and verbal protocol sketches (Figure 95) produced by Student 92 depicted an artefact for boiling water which was designed for the student's favourite soccer player. The post-instruction visual and verbal protocol sketches (Figure 96) depicted different designs of toys for the student's two year old nephew who enjoyed things with mechanical movement. The post-instruction task consisted of sixteen sketches which were slightly more sophisticated and detailed than the pre-instruction task. In addition to this there were some pictorial representations depicted at post-instruction with some annotations. No other notable observations were made.

Figure 95 – Pre Instruction Visual and Verbal Protocols Sketches for Student 92

Figure 96 – Post Instruction Visual and Verbal Protocols Sketches for Student 92
In general, Student 92 was positive about his learning experiences although he often expressed difficulty with tasks. It was obvious from his qualitative comments (Table 21) that he found the tasks to be challenging in nature from an early stage and that he struggled to visualise information in almost all of the tasks. The student’s enjoyment and value taken from the activities coupled with his consistent difficulty visualising information and generating ideas suggested why he was classified as a “low positive mover”.

Table 21 – Selection of Comments for Student 92

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>Need more time</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>I found it very difficult visualising a mirror image. I found myself drawing the same things on both sides</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>I found it quite difficult to visualise some parts. The hardest one I found was the spoon. I tried doing it from different angles but still found it quite hard. I found this a very beneficial exercise. I think it has improved my sketching somewhat</td>
</tr>
<tr>
<td>Transfer</td>
<td>It was a good activity. It really got you thinking of proportion and size. The shadow exercise was very difficult, I found it hard to visualise the shadows</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>I found this exercise very beneficial. I tried to imagine the object being rotated around and I think this really helped me</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>Difficult trying to visualise and determining the right shade of thickness for each part of the clothes</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>Pen was tricky to work with. Enjoyed the exercise. Gave you a chance to be creative. Gave you complete freedom</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Very good activity. Very enjoyable</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>Trying to come up with ideas was difficult</td>
</tr>
</tbody>
</table>
5.4.3.8 Commentary for Student 11

Student 11 rated his pre-instruction sketching ability as “Poor” and post-instruction ability as “Poor”. He was classified as a “low positive mover” based on a weighted shift of 36 with pre-instruction rank of 138 and post-instruction rank of 120.

Similar to Student 92, the pre and post-instruction conceptual sketches (Figure 97) produced by Student 11 did not suggest any significant improvement in sketching quality. Both pre and post-instruction sketches lacked creativity and were basic in nature although there was an attempt made on both occasions to sketch pictorially. A sole significant difference between pre and post instruction was an increased number of sketches which suggested increased levels of exploration and synthesis.

![Student 11 Pre-Instruction Sketch](image1)
![Student 11 Post-Instruction Sketch](image2)

Figure 97 – Pre and Post Instruction Conceptual Task Sketches for Student 11

The pre and post-instruction cognitive data (Figure 97 and Figure 98) for the visual and verbal protocol analysis showed a decrease in the total number of cognitive actions between pre and post-instruction. There was a significant decrease in Executive Control actions at post-instruction. There were generally no differences in Exploration and Generation actions between pre and post-instruction. This could suggest why the student was classified as a “low positive mover”.

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Figure 98 – Plots of cognitive actions for Student 11
Figure 99 – Breakdown of cognitive actions for Student 11
The pre-instruction visual and verbal protocol sketches (Figure 100) produced by Student 11 depicted an artefact for boiling water which was designed for the student’s brother who lives in Australia. The post-instruction visual and verbal protocol sketches (Figure 101) depicted different designs of toys for the student’s four year old neighbour who enjoyed everything related to sport. The depictions generated for both pre and post visual and verbal protocols were conceptual in nature. However, the level of sophistication of the sketches was poor on both occasions with limited detail and all sketches represented two-dimensionally.
The qualitative comments (Table 22) provided by Student 11 provided a very interesting insight into his learning experience. Student 11 generally commented on the educational value of the activities throughout and generally didn’t critique his own progression or development. The educational value which the student placed in the activities coupled with no real evidence of self-reflection would also suggest why he was classified as a “low positive mover”.

Table 22 – Selection of Comments for Student 11

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Recognition</td>
<td>Provides a good example to improve your ability to get distances and good to get people involved in drawing and understand it’s not just mechanical</td>
</tr>
<tr>
<td>Enquiry</td>
<td>Sketching provides an ability to give a better understanding of the drawing in different views and helps visualise proportions</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>It was good to be able to draw our own drawings rather than being given something to draw</td>
</tr>
<tr>
<td>Transfer</td>
<td>Very beneficial as we are often translating an image to our drawings and paper. Makes lectures interesting as well</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>Found it hard to sketch circles. Also, it was more difficult than other objects to add your own design to and change it around.</td>
</tr>
<tr>
<td>Auxiliary Enlightenment</td>
<td>It brings a picture to life and changes the whole profile of the picture like doing this in the lab as it is interesting</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>This was good as we could take anything we wanted and add pieces to make it look different and interesting. Got people up and engaged in lesson as well</td>
</tr>
<tr>
<td>Journey (b)</td>
<td>Background evolved more than anything else</td>
</tr>
<tr>
<td>Auxiliary Journey</td>
<td>Little bit confused as to the purpose of this exercise. Imagination?</td>
</tr>
</tbody>
</table>
5.4.3.9 Commentary for Student 108

Student 108 rated his pre-instruction sketching ability as “Very Poor” and post-instruction ability as “Poor”. He was classified as a “negative mover” based on a weighted shift of -99 with pre-instruction rank of 12 and post-instruction rank of 107.

The pre and post-instruction conceptual sketches (Figure 102) produced by Student 108 were strikingly similar as the student sketched a robot which had almost the exact same features on both occasions. Judges comments for the pre-instruction sketch generally favoured the functionality of the character with particular reference to the spring illustrating the character’s spine and hinging action of the elbows. This level of detail appeared to be absent in the post-instruction sketch and it was generally considered less creative by the judges. It was interesting that the student produced two extra sketches in the post-instruction activity but these did not appear to be valued by the judges.

The pre and post-instruction cognitive data (Figure 103 and Figure 104) for the visual and verbal protocol analysis generally showed an increase in the total number of cognitive actions for Executive Control and Exploration at post-instruction. The Exploration actions at post-instruction were somewhat comparable with Middleton’s (2008) expert while the Generation actions appeared to be consistently high at post-instruction.
Figure 103 – Plots of cognitive actions for Student 108
Figure 104 – Breakdown of cognitive actions for Student 108
The pre-instruction visual and verbal protocol sketches (Figure 105) produced by Student 108 depicted a device for boiling water which was designed for the student’s father who is a plumber and he likes his pint of Guinness. The post-instruction visual and verbal protocol sketches (Figure 106) depicted the design of a hand held quiz game for a child which promoted the Irish language. The depictions generated for the pre-instruction task were based on the student’s detailed knowledge of plumbing systems. There was an increase in the number of sketches generated at post-instruction. These included some sophisticated pictorial sketches in addition to several annotations.

Figure 105 – Pre Instruction Visual and Verbal Protocols Sketches for Student 108
The qualitative comments (Table 23) from Student 108 provided significant indications as to why he was classified as a “negative mover”. The student’s previous sketching experiences had a very negative impact on his self-belief and motivation to develop his sketching ability. The student stated that he believed his sketching was very bad and that he “did not have it in the hands” because that was what a previous teacher of his had told him. This is despite the fact that his pre-instruction sketch ranked among the best out of all students at number 12. The student’s comments within the activities were generally positive and it was apparent that the student was comfortable with the activities at an early stage but once he progressed to conceptual sketching at “Journey” he lost confidence again and his post-instruction comment validate this conclusion.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction Comment</td>
<td>I wouldn’t have the patience to sketch... When I was at school the teacher told me you wouldn’t be able to sketch... It's all in the hands he used to say...I don’t like sketching to be honest now...</td>
</tr>
<tr>
<td>Recognition</td>
<td>It showed me that it is easier to draw in stages rather than the whole picture</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>It makes it easier as if it was on the board I would personally find it difficult to draw. It was simple but effective</td>
</tr>
<tr>
<td>Enquiry</td>
<td>Transferring from the picture plane to the sheet was tricky as I wouldn’t think of myself as a sketcher but I need to slow down and draw what I see and not let my pencil run past where I should stop. It was an eye opener in simple ways to have a picture plane</td>
</tr>
<tr>
<td>Auxiliary Enquiry</td>
<td>I found it quite tricky to get used to but once I did I thought that it wasn’t too bad. My sketching is quite poor so any activity in which it improves it is very beneficial</td>
</tr>
<tr>
<td>Transfer</td>
<td>Building on the simple sketch has developed my spatial awareness I feel. The sketching of the sun tested me in where I should place my sketches</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>Being able to change the orientation was helpful because some of my sketches were not to a similar scale as the original</td>
</tr>
<tr>
<td>Journey (a)</td>
<td>There was more time wasted thinking of what to do than on what we actually drew</td>
</tr>
<tr>
<td>Post-Instruction Comment</td>
<td>Highlighted the amount of work I need to do myself to raise my personal standard</td>
</tr>
</tbody>
</table>
5.4.3.10 Commentary for Student 136

Student 136 rated his pre-instruction sketching ability as “Good” and post-instruction ability as “Good”. He was classified as a “negative mover” based on a weighted shift of -143 with pre-instruction rank of 92 and post-instruction rank of 187. Interestingly, Student 136 was one of the students who classified himself as an expert sketcher and volunteered to participate in the focus group sessions during Preliminary Study 1.

The pre and post-instruction conceptual sketches produced by Student 136 (Figure 107) were very similar in appearance and consisted of various abstract depictions. However, on analysis of both sketches there was little evidence of utilisation of the geometries which the students were required to incorporate into their character. Although the sketches did appear to be somewhat creative and detailed, it was obvious that they did not meet the requirements of the brief.

The pre and post-instruction cognitive data (Figure 108 and Figure 109) for the visual and verbal protocol analysis revealed a noticeable decrease in the number of Executive Control actions at post-instruction. The Generation and Exploration actions appear similar for both sketching episodes. No notable comparisons were made with Middleton’s (2008) expert.
Figure 108 – Plots of cognitive actions for Student 136
Figure 109 – Breakdown of cognitive actions for Student 136
The pre-instruction visual and verbal protocol sketches (Figure 110) produced by Student 136 depicted a device for boiling water which was designed based on the evaporation of sea-water (Sketch 1). However, after about three minutes of the activity the student resorted to drawing objects which were in front of him such as a plastic bottle and felt tipped pen. It was very obvious that the student preferred to draw observationally and this was reinforced by his verbal comments including examples such as “I’m kind of stuck with what I’m meant to be drawing…”, “Looking at the computer... Looking for ideas...”, “Just looking around for different things to be drawing and to be doing to entertain myself...”. Although the student did sketch well represented, detailed drawings of the artefacts in front of him such as the plastic container and the pen, it should be noted he failed to meet the brief. This was also evidenced in the pre and post-instruction Conceptual Sketches described previously.

The post-instruction visual and verbal protocol sketches (Figure 111) depicted the design of a steam engine for the student’s young cousin. It was noticeable during this activity that the student engaged in significantly more conceptual sketching than pre-instruction. This could have happened for several reasons. Perhaps the student changed his value system and realised he should develop his conceptual sketching skills or perhaps the student felt more comfortable with the post-instruction design.
brief. However, it was noteworthy that the level of sophistication of the post-instruction sketches was significantly reduced. There was a mixture of both two-dimensional and pictorial depictions with evidence of difficulty in communicating correct proportionality in the pictorial depictions.

The qualitative comments (Table 24) provided by Student 136 provided a greater insight as to why he was classified as a “negative mover”. Similar to Student 108, the previous sketching experiences had a negative impact on his performance. However, both students’ previous experiences were distinctly different. Student 136 studied art at second level and was very competent at observational drawing. This was obvious in his pre-instruction depictions of the milk carton and felt tipped pen. However, his reluctance to apply himself to solving conceptually derived sketching briefs suggested a reluctance to progress away from observational drawing. This was also evident in the students comments presented in Table 23 particularly where he claimed he was “just messing around with drawings” at “Auxiliary Journey” and he totally disagreed with some other sketching activities for the module of study in the post-instruction comment. It was also notable that the student generally didn’t
provide any comments for the sketching activities which suggest a lack of motivation and apathy.

Table 24 – Selection of Comments for Student 136

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction</td>
<td>I’d rather be given something to draw it…didn’t really understand what the idea behind it is…I’d rather have a purpose behind what I draw and know what I’m drawing rather than just making it up as I go along. What did I think of the drawings? They are sketches…They are just rough…Nothing great…Nothing rubbish… I rather have something in front of me to draw…Rather than drawing things off my head…And trying to speak and talk as well without knowing…</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>Very handy for transfer of dimensions using pencil</td>
</tr>
<tr>
<td>Enquiry</td>
<td>Think the exercise was a bit big – took too much to fill the page. It resulted in me just slopping colour on the page</td>
</tr>
<tr>
<td>Auxiliary Transfer</td>
<td>I was just messing around with drawings</td>
</tr>
<tr>
<td>Post-Instruction</td>
<td>I truly didn’t agree with starting to do interpenetration with a freehand sketch… I think this can only be used when your are very familiar with the principles and thoroughly understand the concept</td>
</tr>
<tr>
<td>General Feedback</td>
<td></td>
</tr>
</tbody>
</table>
5.4.3.11 Commentary for Student 60

Student 136 rated his pre-instruction sketching ability as “Not Sure” and post-instruction ability as “Poor”. He was classified as a “negative mover” based on a weighted shift of -185 with pre-instruction rank of 136 and post-instruction rank of 229.

The pre and post-instruction conceptual sketches (Figure 112) produced by Student 60 were similar in nature; both were pictorially represented and contained multiple sketches with moderate detail. Significantly, it was noticeable that both sketches were generally missing the fundamental geometries which the brief required the students to synthesise into their conceptual character. This was key factor in the judge’s decisions and accounted for the poor ranking of both sketches.

The pre and post-instruction cognitive data (Figure 113 and Figure 114) for the visual and verbal protocol analysis showed an increase in both Generation and Exploration actions at post-instruction while the number of Executive Control actions decreased. Interestingly, the Exploration and Generation actions evidenced at post-instruction were somewhat comparable to Middleton’s (2008) expert.
Figure 113 – Plots of cognitive actions for Student 60
Figure 114 – Breakdown of cognitive actions for Student 60
The pre-instruction visual and verbal protocol sketches (Figure 115) produced by Student 60 depicted several design ideas for a device for boiling water for the students favourite television character who was “Fonzie” from “Happy Days”. It became apparent early on in the exercise that the student wasn’t taking the task seriously. There were periods where the student engaged in episodes of singing and the task became a story depicting the adventures of the television character and didn’t really focus on solving the brief.

![Figure 115 – Pre Instruction Visual and Verbal Protocols Sketches for Student 60](image)

The post-instruction visual and verbal protocol sketches (Figure 116) depicted the design of an educational based toy for the student’s young sister but the sketching episode quickly changed to the design of sports equipment for the student himself. This lack of concentration and inability to solve the given design brief may have been a reason for the student’s significant negative weighting. Although the student did evidence creative thinking and moderately good sketching at pre-instruction, any possible development was hindered by his poor application.
The qualitative comments (Table 25) for Student 60 were peculiar in nature as he was generally positive about all the sketching activities except the conceptual “Journey” activities. In addition to this he generally reflected on his own performance and development. Interestingly however, his pre-instruction and post-instruction comments were negative in nature. At pre-instruction the student was critical of the task and at post-instruction he questioned the relevance of some of the activities. For this interesting student it was concluded that he was such a significantly “negative mover” due to apathy and an inability to correctly approach tasks with particular reference to the pre and post instruction sketching briefs.

Table 25 – Selection of Comments for Student 60

<table>
<thead>
<tr>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Instruction Comment</td>
<td>What did I think of the activity? Ah it was alright... The thinking out loud thing... I don't think it made much of a difference but... If you had something better to come up with...The whole kettle thing... You're not really going to have too many things on that... It was a bit distracting as well with other people talking beside you...You get some ideas out there but I don't know...</td>
</tr>
<tr>
<td>Auxiliary Recognition</td>
<td>I felt it was a useful doing it because it made me pay more attention to the detail in the drawings and I found small differences in my own sketch left it looking different to the original</td>
</tr>
<tr>
<td>Enquiry</td>
<td>Balancing the objects on the picture plane was tricky and kind of led to mistakes in the sketch</td>
</tr>
</tbody>
</table>
Transfer

This activity made me think actually transferring an image with relation to size and location of other images then shadowing made me think of redrawing the image from a different direction.

Auxiliary Transfer

Didn’t really get much time to look at the pin so my sketches kind of varied in shape. Don’t know if that helped my sketches or not. I think overall moving to redraw the object again and again definitely helped my sketches because I found the last few sketches I did were better than the first few.

Auxiliary Enlightenment

I found this activity helpful for sketching the person and using shading to show shapes and shadows.

Journey (a)

Developed my creativity I’d say more than sketching with the markers and drawing up against the wall. I found it hard to concentrate on the actual sketch and concentrate on more than one idea.

Auxiliary Journey

Helps you thinking outside the box but in developing your sketching I think it doesn’t help that much.

Post-Instruction Comment

I didn’t feel it was all relevant, maybe more practice drawing specific objects in specific areas would improve accuracy more than having to draw a lot of different shapes quickly.

The commentary for the selected individual students was the final phase of analysis which was carried out. A summary of the findings for the Primary research study are presented in the next section.

5.5 Summary of Findings

A summary of the findings presented in this chapter is presented below. These findings provide the basis for discussion in the next chapter.

- A large number of the students perceived their ability to freehand sketch improved as a result of completing the model of sketching activities. This was evidenced in the post-instruction feedback provided by students (Appendix 24 & 25, Volume 2) where students generally claimed that the activities were “beneficial and worthwhile” and that they also noticed “improvement in their sketching ability”. Examples include “My sketching ability has improved because I was constantly practicing” (Student 18), “I feel my sketching improved immensely since we started sketching in the labs” (Student 126) and
“Really enjoyed the labs. Very good at giving us confidence in our ability” (Student 55).

- The results of the Comparative Pairs Assessment of students’ pre and post-instruction Conceptual Sketching Tasks revealed that student’s post-instruction sketches were significantly better. The Comparative Pairs Assessment not only helped in validating the model of activities in developing sketching ability, it also enabled the magnitude of students’ improvement to be determined. Visual examination of students’ pre and post-instruction sketches also highlighted the effect of completing the model of activities. Positive movers generally improved their ability to sketch pictorially, with greater levels of detail and complexity in addition to increased levels of exploration being evidenced. These areas of improvement all align with literature concerning expertise in freehand sketching (Jonson, 2005, Verstijnen, 1998b, Kavakli et al., 1999).

- The calculated weighted shift from pre to post-instruction revealed that the students who improved most were those whose sketches were considered to be the best at post-instruction. Therefore, the students with post-instruction rank positions near the top generally were not very good sketchers at pre-instruction. This further validates the model of activities as it provides evidence that students with poor or average sketching ability can be improved significantly with appropriate instruction.

- Based on 1,607 comments from the Comparative Pairs Assessment it was found that the most common assessment criteria applied included creativity, synthesis of shapes and quality of sketching. Similar criteria have been applied using criterion referenced assessment by Yang (2007) and Goldschmidt and Smolkov (2006), therefore validating the assessment
method. However, the application of Comparative Pairs Assessment also enabled further criteria to be identified including “Personality and Realism” and “Sophistication” of sketches.

- The ratings and comments provided for each activity within the model provided interesting observations. Generally the “negative movers” rated their sketches to be better than the “positive movers” for each activity. The “negative movers” valued the initial observational drawing activities higher than the “positive movers”. Once the activities progressed away from observational drawing towards conceptual sketching the “positive movers” valued the activities greater. This was evidenced in the students’ feedback comments. Examples of both “positive movers” and “negative movers” comments include the following: “Very intense activity but very rewarding” (Student 55, Significant Positive Mover, Enlightenment feedback comment) and “I thought this activity was more of a memory test than a sketching exercise” (Student 56, Negative Mover, Enlightenment feedback comment). The researcher scores revealed the “negative movers” scored higher for the initial observational drawing activities and there were no clear trends evident in the subsequent conceptual based sketching activities.

- Psychometric tests revealed a statistically significant increase in “Storage Test” scores for the entire group with medium effect size. This suggests that students generally developed their ability to be flexible when generating new and different solutions to figural problems. This was also found in Preliminary Study 3.

- There was a significant increase in “Synthesis” and “Exploring Constraints” actions for the entire group between pre and post-instruction.
• Visual examination of the pre and post-instruction “Visual and Verbal Protocol” sketches and the “Conceptual Sketching Task” sketches revealed some interesting observations. There was a visually striking improvement in the quality, type and detail of sketches produced by the significant and medium “positive movers”. It was more difficult to define where the improvement in sketching occurred for the “low positive movers” although it was observed that these students generally produced more sketches and engaged in increased levels of exploration. The type of sketching for the “negative movers” tended to be of a generally good standard but with no real evidence of any improvement.

• During the visual and verbal protocols, the “significantly positive movers” generally sketched creative conceptual ideas and the “low” to “medium positive movers” generally sketched memorised visual information such as various forms of machinery. The type of sketching approach by “negative movers” was more difficult to define but generally there was evidence of a reluctance to progress away from observational type drawing or memory sketching from memory. This was particularly evident in Student 136. This student studied art education at second level and he was a very good observational drawer. This was evidenced during his pre-instruction visual and verbal protocols where after five minutes he resorted to drawing a milk container and pen which he observed in front of him. He consistently made reference “looking around for something to draw” and although he made an attempt to draw conceptually at post-instruction, the quality of his sketching was relatively poor.

• A number of conclusions can be made from the qualitative data gathered throughout the model of activities and visual and verbal protocols. In general the “significantly positive movers” were very positive about each activity but also tended to be very reflective and critical about their performances. E.g. “It
helped me to learn more about shading and it helped me to look at the object in greater detail so I could sketch it in different positions” (Student 83, Auxiliary Transfer feedback comment). This would also suggest why the “positive movers” generally rated their performance lower than the “negative movers”. The “low positive movers” generally tended to be positive about their learning experience but appeared passive and didn’t evidence any self-appraisals. The “negative movers” generally tended to be less positive about their entire learning experiences. E.g. “I was just messing around with the drawings” (Student 136, Auxiliary Transfer feedback comment).

- The previous sketching experiences seemed to effect the progression of “negative movers” as they generally didn’t tend to fully apply themselves when solving the pre and post-instruction briefs. This is evidenced by Student 136 who studied art education and was reluctant to draw conceptually and Student 108 who appeared to lack confidence and mentioned during his pre-instruction visual and verbal protocols that his second level teacher told him that he’d never be any good at sketching because he “didn’t have it in the hands”.

The findings presented in this chapter formed the basis for a discussion which aimed to address the initial research questions set out at the start of the study. This discussion is presented in the next chapter.
6 DISCUSSION
6.1 Introduction

The strengths of the research lie in the design of the model of applied sketching activities and the evaluation of its effectiveness using several methods. Although the research was initiated due a limited understanding surrounding the development of sketching ability in second level technology subjects the focus of the problem quickly centred on Initial Technology Teacher Education (ITTE). Carrying out the study with undergraduate students of ITTE provided the necessary dynamic to design, refine and evaluate the effectiveness of the model of activities. Almost 280 participants took part in the entire study and their prerequisite knowledge of educational best practice provided a comprehensive source of feedback.

In order to discuss the broad range of findings from the Primary Research Study this chapter is divided into five main sections. The discussion firstly considers what constitutes freehand sketching and this is followed by a review of the applied model of sketching activities. The third section considers the findings from different methods which were applied to measure sketching ability and this leads to an analysis of sketching expertise in Initial Technology Teacher Education (ITTE). The final section presents recommendations for the development of freehand sketching skill within technology education in Ireland.

6.2 Understanding Freehand Sketching

The study initially set out to explore how freehand sketching skill could be developed. This was in response to the design and implementation of two new technology subjects at senior cycle in the Irish second level system. The subjects have integrated creative design based components which require the ability to freehand sketch as a problem solving and communication tool.
Subsequent to a review of the pertinent literature relating to different aspects of freehand sketching skill a number of gaps in knowledge were identified. It was found that the literature described two modes of communicating graphical representations using paper and pencil. These modes of representation are “drawing” and “sketching”. A continuum which ranges from “observation” to “memory” and “imagination” (Fish, 1990) was identified. The communication of “observed” information is classified as “drawing” while cognitive modelling of visual mental images in the “imagination” and their subsequent external communication is classified as “sketching”. In order to freehand “sketch”, it is beneficial to be able to freehand “draw” what is perceived first. This enables the construction of “graphical libraries” (Storer, 2008) which can be accessed at a later stage during conceptual “sketching”.

Analysis of existing courses of professional development which were completed by practicing teachers in order to develop their ability to freehand sketch revealed that the activities were focused primarily focused on observational “drawing”. These activities were merited as they helped to build the practicing teachers necessary skills required to progress towards being able to freehand “sketch”.

Teachers need to understand the differences between “drawing” and “sketching”. Developing the perception based skills involved in observational “drawing” is critical for developing the ability to conceptually “sketch”. The pre-instruction comment from Student 136 provides evidence as to why teachers need to understand the differences between drawing and sketching. Student 136 was told by his second level teacher that he would never be good at freehand sketching because he didn’t “have it in his hands”. This attitude and lack of understanding can be detrimental to student’s confidence and performance as was evidenced with Student 136 who was a “Negative Mover”.
In order to develop any models of instruction which promote the development of freehand sketching skill it is important that teachers understand the underlying cognitive factors involved. The significance of the model of activities applied in the study is discussed in the next section.

6.3 Developing Sketching Ability

Research (Verstijnen, 1998b) claims that there is a lack of scientifically validated models of instruction which promote the development of sketching ability. As a result of analysing the literature associated with freehand sketching and the findings of the Preliminary Studies, the model of drawing and sketching activities (Figure 117) was proposed. This new model was implemented and its effectiveness evaluated during the Primary Research Study.

Prior to discussing the measured effectiveness of the model it is important to understand the significance of its design. The model progresses from left to right where the perception based “drawing” activities on the left are controlled and reflective in nature. In contrast, the conceptual “sketching” activities on the right are automatic and reflexive.
The strength of the model lies in its potential to promote student’s progression across the three stages of development through perceived, memorised and conceptualised activities. The perception based activities build students “graphical libraries” (Storer, 2008) as they are constantly able to refresh vivid perceptual snapshots while composing their drawings (Fish, 1990). The memory focused activities in the centre of the model develop student’s ability to access their “graphical libraries” through “visual mental imagery” (Borst, 2008) and to communicate these through sketching. The final conceptually focused phase of the model promotes students ability to manipulate and synthesise their “graphical libraries” through tasks which are imaginative and reflexive in nature.

This research presents empirical evidence that illustrates the transition from perception to memory and imagination with varying degrees of certainty. Performance in the observationally focused activities was consistent while considerably more variation was seen once the transition to the more cognitively challenging conceptual based activities occurred. This was a significant finding.

The findings which described the students learning experiences while completing the model of activities validate the importance of the three stages of progression and the different cognitive focus for each. It was found that the “Positive Movers” were generally positive about their entire learning experience and valued the educational significance of what they were doing. This was supported by the mean value scores provided by all students at the end of each activity in addition to their qualitative feedback comments. In addition to being generally positive it was evident that the significant “Positive Movers” were very self-reflective and critical of their performance at the end of each activity.
In contrast to “Positive Movers”, the “Negative Movers” tended to be more apathetic about their learning experience. Their comments were generally positive during the early perception based activities but they became less positive during the memory and conceptual focused activities. This was also supported in their lower mean value ratings for the activities.

In terms of second level education, this finding should encourage teachers to stimulate pupil’s levels of motivation prior to and during sketching activities. It is important that teachers encourage pupils to evaluate their sketches and performance and to realise what they did well and what they need to improve upon. If this level of self-reflection and analysis is encouraged, it will help students to realise the steps involved in learning sketching skill.

The educational significance of the model of activities must not be underestimated. It promotes the development of a complex cognitive and psychomotor skill from a controlled and reflective process to a process which is automatic and reflexive (Satpute, 2006). The model also embraces and values the objectives for freehand sketching within DCG as “tool for explaining and solving problems” (D.E.S., 2007a).

In order to examine the effectiveness of the model in developing sketching ability in undergraduate students of technology education it is necessary to consider the findings of different measures which were applied during the study. These are discussed in the next section.

6.4 Measuring the Development of Sketching Ability

The application of various methods to measure the development of different facets of students sketching ability as a result of completing the model of activities was novel. The use of Comparative Pairs Assessment to order pre
and post-instruction conceptual sketches enabled the improvement of student’s sketching ability to be measured. This approach validated the effectiveness of the model of activities as it was found that a significant number of students scored better in their post-instruction sketching task.

The recording and coding of 1,607 judges’ comments enabled the common criteria which were applied to be identified. The three most frequently applied criteria included creativity, synthesis of geometries and quality of sketching. These validate the criteria applied by other researchers (Yang, 2007, Goldschmidt & Smolkov, 2006) in examining design sketches. It is therefore important that these criteria should be considered when designing criterion referenced assessments of pupil’s sketches in DCG.

The novel application of Comparative Pairs Assessment has significant implications for any future research which might focus on the development of sketching ability or other complex creative skills which are difficult to measure. It provides researchers with a valid and reliable method for examining the effect of strategic instruction.

In order to evaluate the effect of the model of activities in developing different aspects of sketching ability, the next section defines the characteristics associated with sketching expertise within Initial Technology Teacher Education (ITTE).

6.5 Sketching expertise within ITTE

The application of different methods during the study enabled the effectiveness of the model of activities in developing different aspects of sketching behaviour and cognition to be established. Several aspects of the findings aligned with literature concerning expertise in freehand sketching.
The significance of these is discussed in relation to development of sketching ability within second level schools.

6.5.1 Sketching Behaviour and Cognition

The findings from the psychometric tests and visual and verbal protocols provided an insight into various aspects of students sketching behaviour and cognition. The significance of these findings is discussed in the following sections.

6.5.1.1 Cognitive Tests

Subsequent to completing the model of sketching activities a significant increase in “Storage Test” scores of a large number of students was recorded. Even though there was no differences found between “Positive Movers” and “Negative Movers” the finding is still considered as important. In general the finding means that the students were better able to generate new and different solutions to figural problems. The educational significance of this is important as it indicates that developing the ability to freehand sketch aids in the ability to solve problems graphical problems not only in DCG but also other subjects such as mathematics.

6.5.1.2 Visual and Verbal Protocols

Although the literature suggests that sketching expertise is associated with a higher number of expert cognitive actions, no significant differences were found between the two groups of students. However, when the visual and verbal data were further analysed several differences in the types of sketching behaviour evidenced at pre and post-instruction were observed.
It was found that the “Positive Movers” generally exhibited similar trends in their post-instruction cognitive actions as Middleton’s (2008) expert especially in terms of Exploration and Generation actions. These trends for a “significant positive mover” are illustrated Figure 118. It is evident that the Exploration actions started at a high level and decreased as the task progressed until the problem was solved. In contrast, the Generation actions started low and gradually increased as the brief was being solved. These findings for the Exploration and Generation actions validate Middleton’s (2008) expert. However, it is more difficult to identify similar levels of Executive Control with Middleton (2008). The levels of Executive Control for the “Positive Movers” were generally constant throughout. Based on these findings it can therefore be concluded that the plot in Figure 118 generally illustrates the cognitive actions of expert sketchers within ITTE. The significance of this “ideal” is important for teachers of DCG as it provides an insight into how pupils should be encouraged to approach design based sketching problems.

Figure 118 – Post instruction plot of cognitive actions for Student 125
Analysis of the conceptual sketches produced by each student at pre and post-instruction revealed significant differences in the type and number of sketches produced. The “Positive Movers” generally produced much more sophisticated sketches at post-instruction which included a number of pictorially represented sketches with high levels of detail. This correlates with literature concerning expertise in freehand sketching (Kavakli et al., 1999). In contrast, there were no significant differences in the type of sketches produced by “Negative Movers”.

During the visual and verbal protocols, the “significantly positive movers” generally generated sketches which were based on imaginative and creative ideas. The “low” to “medium positive movers” generally sketched visual information such as various forms of machinery which was based on their “graphical libraries” (Storer, 2008) of visual mental images. The sketching approach by “negative movers” was more difficult to define but generally there was evidence of a reluctance to progress away from observational type drawing or sketching memorised visual images. These findings validate the design of the model of sketching activities which is composed of three phases. Those students who were “positive movers” showed evidence of having progressed through all stages while there were indications that “negative movers” may not have reached the same levels of progression.

6.6 Implications of the Research Study

The findings of the study are critical in order to understand how freehand sketching ability can be developed in technology subjects in the Irish second level system. This was the first empirical study of its kind to have taken place in which development of sketching skills which are fundamental to technology based subjects were examined.
It was conclusively established that it is possible to develop the ability to freehand sketch as a multi-purpose sense-making tool in DCG. However, the research identified that the magnitude of development is dependent on several factors which include levels of motivation and students previous learning experiences.
7 CONCLUSIONS
7.1 Conclusions

The following conclusions were drawn from the research study:

- The ability to freehand sketch is a teachable skill. The magnitude of development is dependent on students’ levels of engagement and intrinsic motivation to improve their sketching skills. Previous learning experiences including subjects studied at second level and the influence of teachers during previous sketching episodes were also found to be influencing factors.

- A model of drawing and sketching activities was designed, refined and empirically evaluated. The model facilitated the development of sketching expertise and ranged across a continuum from observation to imagination.

- Students who evidenced greater levels of improvement in sketching ability were generally highly motivated, self-reflective and they valued the educational significance of the activities which they completed.

- Cognitive tests indicated that the model of activities was effective in developing student’s ability to generate new and alternative solutions to figural problems.

- The quality of students sketching and their ability to express creativity improved significantly as a result of completing the model of sketching activities. This was particularly evident in the pre and post
conceptual sketching exercises where the students were required to
engage in complex cognitive modelling of visual mental imagery and
communicate this through the medium of freehand sketching. The
post instruction sketches were generally more sophisticated, creative
and communicated high levels of complexity.

- This research study provides a validated model for developing
  sketching expertise in undergraduate students of technology
  education. As the research was influenced by the introduction of new
  technology subjects at second level, future studies should explore how
effective the model is when applied within these subjects (studied
typically by 15-18 year olds). This could be done using similar pre
and post instruction methods such as those applied in the Primary
Research Study and these would provide an insight as to how valid
the model of activities is for second level.

- In addition to validating the effect of the model, it is important that a
deeper insight into pupils learning experiences should be obtained by
applying suitable methods such as non-invasive observational
techniques (Stables, 2008). By carrying out these further studies it is
envisioned that an even greater insight into how sketching expertise
can be developed in second level pupils will be obtained.
8 FUTURE WORK
8.1 Future Work

The focus of future research stemming from the conclusions of the study is outlined as follows:

1. The study was initiated to attain a better understanding of how freehand sketching ability can be developed in second level technology based subjects. The findings of the study provide an empirically proven model of instruction which needs to be applied and evaluated within Design and Communication Graphics (DCG) at second level.

2. The study was primarily concerned with the evaluation of students sketching behaviour and cognition at pre and post-instruction. In order to gain an insight into students cognition and behaviour during the model of sketching activities, observational techniques (Stables, 2008) for examining students learning should be considered.

3. The study found that it was generally difficult to explain why some students appeared to digress as a result of completing the model of activities. Further statistical analysis of the qualitative data which was gathered throughout the study should be conducted in order to further comprehend this apparent disimprovement in sketching ability.

4. Further analysis of the data gathered during the visual and verbal protocols should focus on what stimulated each sketching episode during the activities in addition to examining student’s ability to access and communicate imagery stored in long term memory.
5. The study highlighted that some students had underlying beliefs and misconceptions surrounding freehand sketching due to past experiences. These beliefs, and in particular those which stem from negative experiences may effect the ability to develop expertise in freehand sketching. Future research should examine student sketching experiences and current methods of instruction at second level. This research should mirror that of Hope (2008) through a longitudinal study in order to further comprehend the values and beliefs surround freehand sketching which students bring to third level education.

6. Forming, manipulating and synthesising “graphical libraries” are critical in developing the ability to freehand sketch. It should be considered that the development of these graphical libraries may be possible through other senses within the “sensory system” of the “cognitive architecture” (Stillings, 1995) that don’t involve vision. Future research should explore the role of haptics in building these geometric libraries. Experiments in mental imagery such as those described where reaction times and degrees of complexity of physical objects are measured may provide indicators in relation to building geometric libraries.

7. Augmented reality involves a combination of virtual reality displays with real world environments (Connolly, 2010). This is a relatively new and exciting technology and it would be worthwhile considering its possible benefits in building “graphical libraries” and the impact this might have on the ability to freehand sketch.
9 PUBLICATIONS
9.1 Associated Publications

The following publications have been produced as part of the research study.

Conference Paper Publications

- Lane, D., Seery, N., Gordon, S., Examining Sketching Ability within Initial Technology Teacher Education, in Graphicacy and Modelling, E. Norman, Seery, N., Editor. 2010: University of Limerick, Ireland
- Lane, D., Seery, N., Gordon, S., Promoting Creative Discovery and Mental Synthesis through Freehand Sketching, Proceedings of Annual MidYear Meeting of Engineering Design Graphics Division, ASEE, Houghton, Michigan, 2010
- Lane, D., Seery, N., Gordon, S., Utilising Freehand Sketching to Amplify Concept Driven Competencies, “Ideas Worth Sharing”, The Design and Technology Association Education and International Research Conference, Keele University, 2010

Journal Publications

Book Chapters


Workshops Presented

- Lane, D., Seery, N. (2010). *A Paradigm to Support the Synthesis of Geometric Libraries through Freehand Sketching*, One day workshop presented to members of the Engineering Design Graphics Division (ASEE) at their MidYear Conference in Houghton, Michigan, October 2010
REFERENCES


11 APPENDICES
APPENDIX 1

Model of Sketching Activities

Recognition and Auxiliary Recognition
Recognition and Auxiliary Recognition were the first of the core activities within the presented model. The rationale and application of these is presented in Table 26 and Table 27 respectively.
Table 26 – Rationale and Application for Recognition

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>The purpose of the activity was to enable students to analyse the relationships between regular and irregular geometries and present these through a scaled composition. This activity mirrors the observational type sketching described by Wilson and Wilson (1980) and promotes the development of a “collective graphic memory” (McKim, 1980).</td>
<td>Recognition was applied in a fifteen minute period during a module lecture. Each student was given an A4 sheet with grid applied prior to the commencement of the activity. Students were advised to copy each piece of geometry (Figure 121) as it was revealed on a large projector screen. The images were projected using a pre-recorded video file (Figure 120).</td>
</tr>
</tbody>
</table>

Figure 120 – Revealing of geometries on to large screen during Recognition

Figure 121 – Revealing of geometries during Recognition

The activity took 15 minutes to complete.
Table 27 - Rationale and Application for Auxiliary Recognition

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
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</thead>
<tbody>
<tr>
<td>Auxiliary Recognition</td>
<td>Based on Lane et al. (2010) Auxiliary Recognition was a new activity that was designed to facilitate the cognitive shift away from observational type sketching. Auxiliary Recognition was a modification of an activity described by Dodson (2007). It was claimed that in order to promote creativity, it is important to start looking at something in an entirely different. As expertise in freehand sketching is associated with high levels of creativity (Verstijnen, 1998b), this activity was designed to promote this at an early stage within the model. As this was considered a creative type activity it was decided that the set up of the classroom environment should be examined prior to commencing the classroom based activities. The seating arrangements were changed from the traditional set-up that aids didactic teaching methods to a more unorganised fashion that would better facilitate a more creative, enjoyable learning experience (Figure 122).</td>
<td>Prior to the commencement of the activity, all students were given an A3 handout (Figure 123) which contained a graphical representation composed of regular and irregular geometries. The students were required to sketch the reverse of the given figure. By doing this it challenged the students to perceive and mentally manipulate the geometry to form a visual image which they then communicated. When the figure was reversed, the students were afforded the opportunity to add a conceptual element to the composition if they wished. The activity took 30 minutes to complete.</td>
</tr>
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</table>

Figure 122 – Classroom setup during sketching activities

Figure 123 – Composition students provided to students during Auxiliary Recognition

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Verstijnen, 1998b
Enquiry and Auxiliary Enquiry

Enquiry and Auxiliary Enquiry are both activities that evolved from the Preliminary Studies. It was important to realise that at this stage, the students had begun to develop observational type sketching skills with some degree of conceptual type modifications.

Both Recognition and Auxiliary Recognition involved copying or modifying 2D visual representations. The logical progression would suggest progressing towards sketching 3D physical objects. Both Enquiry and Auxiliary Enquiry were designed to achieve this. The rationale and application for these are described in Table 28 and Table 29.
Table 28 – Rationale and Application for Enquiry

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enquiry</td>
<td>Enquiry evolved significantly since it was initially applied during Preliminary Study 1. The design and manufacture of a novel and original hands-free 3D to 2D conversion device led to significant results in Preliminary Studies 2 &amp; 3.</td>
<td>Prior to commencing the Enquiry activity, a selection of wooden geometric shapes were purchased and glued together in various ways to form novel configurations (Figure 125).</td>
</tr>
</tbody>
</table>

During the Preliminary Studies, the 3D to 2D conversion device was used to enquire into the geometries that are combined within everyday objects such as mobile phones and handheld devices.

As one of the primary objectives of the student’s module of study was the exploration of principles in plane and descriptive geometry, it was decided not to use everyday artefacts and instead adopt physical models of geometric shapes such as cones, cylinders, rectangular prisms and so on.

The activity took one hour to complete.

Prior to commencing the Enquiry activity, a selection of wooden geometric shapes were purchased and glued together in various ways to form novel configurations (Figure 125).

At the start of the Enquiry activity, the students were given a “3D to 2D” conversion device and were invited to take a couple of the configurations.

The students were shown a video that described the best procedure for drawing on to the picture plane and holding the shapes. Subsequent to this all students were invited to hold the shapes in interesting, complex positions and enquire into the geometries by tracing onto the plane (Figure 126).

After converting the 3D information to the 2D plane, the students were invited to copy the composition on to paper and apply rendering if they wished.

The activity took one hour to complete.

Figure 124: 3D to 2D conversion device

Figure 125: Building the geometric shapes

Figure 126: Tracing on to the plane
Table 29 – Rationale and application for Auxiliary Enquiry

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Enquiry</td>
<td>Auxiliary Enquiry promotes the enquiry into everyday artefacts and the communication of these. The activity was designed as a further progression of Enquiry, in which the geometries of physical 3D compounds were traced onto the transparent 2D plane. The logical progression was to reduce or totally remove the plane and promote the ability to draw a physical composition using perception alone. Auxiliary Enquiry affords the students the opportunity to explore everyday artefacts at home using a pocket sized 3D to 2D conversion device to record critical proportions (Figure 127).</td>
<td>At the end of the sketching class in which the Enquiry activity took place, students were given the following task: “You are required to explore and communicate physical artefacts commonly found at home. You may use the pocket sized 3D to 2D conversion device (Figure 127) to help with taking snapshots of critical proportions. You should populate the sheet with as many artefacts as possible. Apply any rendering as you deem necessary”.</td>
</tr>
</tbody>
</table>

All students were sent an electronic template into which they were required input a photograph of every object that they sketched in addition to their completed sketch. This enabled a comparison to be made between each which would determine any development in their observational sketching skills and ability to Recognise, Enquire into and communicate physical objects. Students were allowed one week to complete their composition.
Transfer and Auxiliary Transfer

Progressing towards the centre of the model of sketching activities, both Transfer and Auxiliary Transfer activities are described in this section. Prior to considering the rationale and description of the activities, it is worthwhile to summarise the progression of the activities thus far.

- **Recognition** was designed to enable students to explore and communicate the relationships between regular and irregular 2D geometries which were revealed on to a large flat screen. Students were provided with grid paper to scaffold their experience.

- **Auxiliary Recognition** was designed to stimulate student’s creativity by encouraging them to look at an object in a different way and mentally manipulate the reverse of a given image.

- **Enquiry** enabled students to explore and accurately “copy” the geometries of physical objects onto a flat 2D plane.

- **Auxiliary Enquiry** was an independent activity in which everyday objects were explored and sketched mainly through perception alone, although a pocket sized picture plane was provided to help alleviate any difficulties.

Subsequent to this brief revision, it is logical to suggest that the activities required progression away from observational type drawing and towards imaginative sketching. This is considered in both Table 30 and Table 31 through the application and design of Transfer and Auxiliary Transfer.
Table 30 – Rationale and Application for Transfer

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transfer</strong></td>
<td>At this point, observational type sketching should almost be “maximally automatic” and based entirely on perception without the need for 3D to 2D conversion devices. In order to establish how comfortable students were with observational type sketching it was decided to use an activity similar to that used in Recognition in a lecture environment (Figure 128).</td>
<td>All students were given a blank sheet at the start of the lecture and were advised that they would be presented with a composition which they had to communicate in a twelve minute timeframe.</td>
</tr>
<tr>
<td></td>
<td>Even though the Transfer activity involved the observation of a 2D composition, it differed considerably from Recognition. No grid was applied, a shorter time frame was given, it was more complex and students were also required to communicate a conceptual element.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>This was be the final observation type sketching activity before the students progressed towards conceptual type sketching activities.</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 128 - Lecture environment for Transfer activity](image)

![Figure 129 - Composition presented for Transfer activity](image)

While students were sketching the composition, they were informed that they had to imagine and communicate the shadow and shade formed by a light source. They could determine the position of the light source themselves. Students were allowed fourteen minutes in total to complete the composition. It should be noted that it was important to have a relatively short timeframe like this as it promoted more reflexive and automatic behaviour.
Table 31 – Rationale and Application for Auxiliary Transfer

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auxiliary Transfer</strong></td>
<td>As the observational type sketching was almost complete following the Transfer activity, Auxiliary Transfer aimed to promote the exploration, mental manipulation and communication of a regular everyday artefact that the students would all be familiar with. The activity was designed to promote the students ability to explore and manipulate an object that they most likely had stored in their “collective graphic memory” (McKim, 1980). Auxiliary Transfer was carried out in a classroom environment.</td>
<td>The students were presented with an image of the object at the start of the activity (Figure 130). The students were then required to sketch this in as many orientations as possible. They were encouraged to be creative with their use of proportionality and also apply rendering where appropriate. An example of a student carrying out the activity is shown in Figure 131. Students were allowed 25 minutes to complete the composition.</td>
</tr>
</tbody>
</table>

Figure 130 – Graphic presented during Auxiliary Transfer activity

Figure 131 – Student carrying out Auxiliary Transfer activity
Enlightenment and Auxiliary Enlightenment

Enlightenment and Auxiliary Enlightenment provided a useful platform towards developing students sketching ability so that it became automatic and reflexive in nature.

The underlying literature influencing the design of the activities at this stage is the notion that sketching is an intermediate between “seeing” and “imagining” (Goldschmidt, 1991, Storer, 2008) and that it stimulates the synthesis of “graphical libraries” (Storer, 2008, McKim, 1980) from memory systems. To this end, the Enlightenment activity was designed to progress memory type sketching abilities. Incidentally, due to the dynamic nature of the study, the Auxiliary Enlightenment developed a different skill set.

Both Enlightenment and Auxiliary Enlightenment are described in Table 32 and Table 33 respectively, in terms of their rationale and application.
Table 32 – Rationale and Application for Enlightenment

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlightenment</td>
<td>Enlightenment was a novel and original activity that aimed to harness and synthesise the previously developed sketching skills through a series of memory exercises.</td>
<td>Each configuration was presented to the students separately.</td>
</tr>
<tr>
<td></td>
<td>In order to explore the synthesis of a “collective graphic memory” (McKim, 1980) and students ability to retain graphical information, it was decided to present students with five separate images (Figure 132) that gradually increased in complexity.</td>
<td>Once each configuration was presented, the students were allowed one minute to examine it and form a visual mental image. The students were not allowed to sketch during this time.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The image of the configuration was then removed and the students were asked to rate how clear their mental image was along a Likert Scale.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once the vividness of the image was rated, the students were allowed two minute to communicate the composition. When complete the students were asked to rate how accurate they thought their image was.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The image was then shown to the students and they were then required to compare both and again rate how accurate their sketch was.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All students were required to justify the last rating with a comment. These were all codified to establish what students were basing their judgements on.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When all five exercises were complete, the students were required to rate their performance, the value they placed in the activity and provide any feedback comments (as in all other activities).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The overall activity took around 45 minutes to complete.</td>
</tr>
</tbody>
</table>
Table 33 – Rationale and Application for Auxiliary Enlightenment

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Enlightenment</td>
<td>Due to the dynamic nature of the study and the constant analysis of student feedback, the nature of the Auxiliary Enlightenment activity was unorthodox in relation to the progression of the other activities.</td>
<td>At the beginning of the activity, a line drawing (Figure 134) was presented using a data projector.</td>
</tr>
</tbody>
</table>

It was found that a number of students expressed concern about their inability to render compositions. In contrast to the Preliminary Studies, this area was somewhat ignored in the original design of the study due to the fact that it was felt that it was necessary to concentrate on building students ability to use sketching as a sense making tool for problem solving and communication. It was envisaged that students might develop this ability through self-exploration.

However, to alleviate these concerns it was decided to devise an activity that would aid student’s development of rendering skills but that it would also be challenging in nature.

The Auxiliary Enlightenment activity took place in the classroom environment (Figure 133).

The students were allowed ten minutes to draw the composition on their sheets. They could determine the scale of the composition themselves.

When complete, the students were given a demonstration describing the appropriate rendering techniques. The students were all required to explore the limits of their soft shading pencils as rough work.

The students were then given a copy of the rendered composition shown in Figure 135 and were subsequently invited to complete the composition by comparison (Figure 133).

The activity took 30 minutes in total to complete.
Journey (a)&(b) and Auxiliary Journey

Referring once again to sketching as a “sense making tool” (Jonson, 2005) that promotes “automatic” and “reflexive” cognitive processing (Stillings, 1995), it was decided to incorporate two group exercises into “Journey” and one individual exercise in Auxiliary Journey.

The three exercises that were completed were designed to promote creativity by devising the tasks so that they forced the students to think and imagine in a conceptual manner.

It should be noted that during any conceptual element of the previous sketching activities that the students completed, it was observed that many students struggled to generate ideas and that many students scanned the room for visual stimuli. However, there were no visual stimuli present in the classroom that could have inspired students. This will be discussed later but it should be made transparent at this stage that based on this observation, a number of creative images were discreetly placed around the walls of the classroom prior to the commencement of Journey (a) and (b). These activities are described in Table 34 and Table 35.
### Table 34 - Description and Application for Journey

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rationale</th>
<th>Application</th>
</tr>
</thead>
</table>
| **Journey (a)** | Journey (a) was a novel activity that was devised based on an association exercise by Dodson (2007).  
The purpose of the exercise was to promote students ability to connect ideas by some common association.  
This was a group activity where students were encouraged to work alongside classmates and quickly generate associated ideas (Figure 136). | At the start of the activity, the students were presented with a series of A0 wall posters. On these posters there were different themes. These included:  
- Geometry on wheels  
- Geometry on Feet  
- Things within things  
- Things on wheels  
- Things on Feet  
The students were given two minutes on each poster and were encouraged to sketch within as many themes as possible.  
It was advised that the activity should be relaxed and that students were not being judged on the quality of their sketching.  
Ten rounds of sketching took place and the activity took 30 minutes in total to complete. |
| **Journey (b)** | Journey (b) was an adaption of a Brainsketching activity described by (van der Lugt, 2002). Brainsketching is an idea generation technique that involves students working together in trying to solve a given brief.  
It was seen as very important that students were able to switch between a more open brief activity as in Auxiliary Journey 1 to an activity whose brief is more specific in Auxiliary Journey 2. | Prior to the commencement of the activity, the students were given the following brief:  
- “How to make travelling fun for children”  
This theme was taken directly from (van der Lugt, 2002). It was considered complex enough for the group of students and it was also somewhat related to their course of study.  
Each student was given an A0 sheet onto which they sketched their initial ideas. In order to build on these ideas, students were required to switch around between each others ideas every two minutes (Figure 137).  
It was stressed that students should explain their ideas to the next person prior to the change over. This was very important. The activity took 20 minutes in total to complete. |

![Figure 136 - Students sketching Journey (a)](image1)  
![Figure 137 - Students pictured during Journey (b)](image2)
The final activity within the core model was Auxiliary Journey. The activity was designed to harness the students sketching skills in addition to stimulating their ability to synthesise geometries.

All students were given an A3 sheet which contained a number of graphical images (Figure 138).

The students were encouraged to conceptualise a sketch that incorporated each geometric shape that was shown.

They were not told what type of sketch to produce. The only criterion was that it had to be creative.

Maintaining the automatic and reflexive nature of the previous activities, the activity took 15 minutes in total to complete.
APPENDIX 2

Weighted Equations Examples

“Positive Mover” Student 31
Student 31 had a Pre-Instruction Rank position of 224 and Post-Instruction Rank position of 1. This was an improvement or “Positive Move”. Based on equation 6.2 (below) the following applied:

- Student 31 moved -223 places (Post Rank Position – Pre Rank Position)
- His Pre-Instruction rank of 224 meant that he had the capacity to move 223 places (as he improved).

\[
\text{Weightedshift} = \frac{\text{postinstructionrank} - \text{preinstructionrank}}{\text{preinstructionrank} - 1} \times -n \quad (6.2)
\]

\[
\text{Weightedshift} = \frac{1 - 224}{224 - 1} \times -274 = 274
\]

“Negative Mover” Student 131
Student 131 had a Pre-Instruction Rank position of 63 and a Post-Instruction Rank position of 103. This was a disimprovement or “Negative Move”. Based on the equation 6.3 (below) the following applied:

- Student 131 moved +40 places (Post Rank Position – Pre Rank Position)
- His Pre-Instruction rank of 63 meant that he had the capacity to move 62 places if he improved.
- However, he disimproved and therefore went in the negative direction.
- Therefore “n-pre-instruction rank position” indicates how many places he could have fallen to where 274 – 63 = 211 places.
\[
Weightedshift = \frac{postinstructionrank - preinstructionrank}{n - preinstructionrank} \times -n
\]  

(6.3)

\[
Weightedshift = \frac{103 - 63}{274 - 63} \times -274 = -52
\]
APPENDIX 3

Coding Scheme for Visual and Verbal Protocols (Middleton, 2008)

<table>
<thead>
<tr>
<th>Category of Procedure</th>
<th>Generation</th>
<th>Exploration</th>
<th>Executive Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td>Retrieval</td>
<td>Exploring Constraints</td>
<td>Goal Setting</td>
</tr>
<tr>
<td></td>
<td>Synthesis</td>
<td>Exploring Attributes</td>
<td>Strategy Formulation</td>
</tr>
<tr>
<td></td>
<td>Transformation</td>
<td></td>
<td>Goal Switching</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monitoring</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Evaluation</td>
</tr>
</tbody>
</table>

**Executive Control**

**Goal Setting (GSet):** Process of establishing an overall goal

**Strategy Formulation (SF):** An indication of a general heuristic for approaching a problem or parts of a problem

**Goal Switching (GSwit):** A change of attention from one aspect of a problem to another

**Monitoring (M):** The process of checking the process of problem solving to establish if goals are being achieved and solution constraints satisfied

**Evaluation (E):** Normative statements about proposals, attributes or strategies

**Generation**

**Retrieval (R):** Retrieval of knowledge from long term memory or the retrieval of information from visual perception of physical objects or visual displays

**Synthesis (S):** The formulation and articulation of a specific proposal to solve a problem or sub-problem

**Transformation (T):** Modifying a proposed idea to enable it to solve a particular problem

**Exploration**

**Exploring Constraints (EC):** The identification of aspects of the problem context or design proposals as containing elements that are perceived as adding to the complexity of the problem

**Exploring Attributes (EA):** Aspects of the problem context or proposed solutions that either facilitate problem resolution or define problem context
APPENDIX 4

A selection of sketches completed by the students during the course of the Primary Research Study is presented in this section. All of the sketches for the study are presented in Volume 2.
Student 30

Pre-Instruction Conceptual Sketching Task

Post-Instruction Conceptual Sketching Task

Exploring Relationships
Recognition
Auxiliary Recognition
Enquiry

Auxiliary Enquiry
Transfer
Auxiliary Transfer

Enlightenment
Auxiliary Enlightenment
Auxiliary Journey
Student 35

Pre-Instruction Conceptual Sketching Task

Exploring Relationships

Recognition

Auxiliary Recognition

Enquiry

Post-Instruction Conceptual Sketching Task

Auxiliary Enquiry

Transfer

Auxiliary Transfer

Enlightenment

Auxiliary Enlightenment

Auxiliary Journey
Student 55

Pre-Instruction Conceptual Sketching Task

Post-Instruction Conceptual Sketching Task

Exploring Relationships  Recognition  Auxiliary Recognition  Enquiry

Auxiliary Enquiry  Transfer  Auxiliary Transfer

Enlightenment  Auxiliary Enlightenment  Auxiliary Journey
Student 82

Pre-Instruction Conceptual Sketching Task

Post-Instruction Conceptual Sketching Task

Exploring Relationships Recognition Auxiliary Recognition Enquiry

Auxiliary Enquiry Transfer Auxiliary Transfer

Enlightenment Auxiliary Enlightenment Auxiliary Journey
Student 85

Pre-Instruction Conceptual Sketching Task

Exploring Relationships

Post-Instruction Conceptual Sketching Task

Recognition

Auxiliary Recognition

Enquiry

Auxiliary Enquiry

Transfer

Auxiliary Transfer

Enlightenment

Auxiliary Enlightenment

Auxiliary Journey
Student 104

Pre-Instruction Conceptual Sketching Task

Post-Instruction Conceptual Sketching Task

Exploring Relationships Recognition Auxiliary Recognition Enquiry

Auxiliary Enquiry Transfer Auxiliary Transfer

Enlightenment Auxiliary Enlightenment Auxiliary Journey
Student 110

Pre-Instruction Conceptual Sketching Task

Post-Instruction Conceptual Sketching Task

Exploring Relationships Recognition Auxiliary Recognition Enquiry

Auxiliary Enquiry Transfer Auxiliary Transfer

Enlightenment Auxiliary Enlightenment Auxiliary Journey