AC 2011-1999: EXAMINING THE DEVELOPMENT OF SKETCH THINKING AND BEHAVIOUR

Diarmaid Lane, University of Limerick
Niall Seery, University of Limerick

Examining the Development of Sketch Thinking and Behaviour

Abstract

Research (Lane et al., 2010b, 2010c), concerning the development of expertise in freehand sketching among students within an Initial Technology Teacher Education (ITTE) programme provides significant indicators that sketching is a teachable skill. Analysing and reporting on any development in sketching expertise can sometimes be difficult and become subject to debate, particularly where casual observations and independent opinions are solely relied upon (Verstijnen, 1998).

This paper reports on the application of a visual and verbal protocol analysis tool (Middleton, 2008) to measure pre-instruction sketching behaviour of third year undergraduate students. Forty one students volunteered to take part in visual and verbal protocol analysis which was carried out simultaneous to a Design and Communication Graphics module. A core element of this module was the development of sketching expertise and the ability to engage in creative discovery within a specially designed model (Lane et al., 2010b, p.88).

Considering the richness of the data gathered using visual and verbal protocol analysis, it was deemed appropriate to solely analyse and report on students who perceived their sketching ability as *"advanced beginner"* (Dreyfus & Dreyfus, 1986). It was found that the *"advanced beginner"* students did not engage in any significant level of exploration during a prescribed sketching based design task. This could be related to their perceived *"poor"* level of sketching ability and their inability to graphically communicate.

The research argument presented in this paper is based on the application of Middleton's (2008) visual and verbal protocol analysis model which attempts to establish the attributes that students need to develop in order to reach a high level of sketching expertise. The findings have potential to inform the future direction of pedagogical practices that focus on freehand sketching within graphical education.

1. Introduction

The research presented within this paper is primarily concerned with examining the sketching behaviour and cognition of perceived novice sketchers within Initial Technology Teacher Education (ITTE) prior to undertaking a specially designed set of activities which aim to develop expertise in freehand sketching.

The body of the paper is presented in four main sections. The first section will provide an analysis of the literature surrounding metrics used to measure expertise in sketching ability. The second section will provide an overview of the research participants and their selection. The third section will detail the application of the chosen measurement tool and the research environment that the experiment was carried out within. The final section will provide an analysis of the gathered data and a discussion of the findings in relation to the associated literature.

Prior to progressing further, it should be noted that the research presented in this paper is an element of an ongoing research project (Lane et al., 2009, 2010a, 2010b, 2010c) that is being carried out within the confines of Initial Technology Teacher Education (ITTE).

2. Measuring Sketching Ability

Literature concerning the measurement of sketching ability is varied and involves methods such as the application of visual mental imagery tasks under controlled conditions (Verstijnen, 1998), observations of children during sketching activities (Hope, 2008) and the application of visual and verbal protocol analysis (Suwa, 1998, Middleton, 2008). Previous research (Lane et al., 2010c) carried out within ITTE suggests that expertise in freehand sketching is associated with high levels of creativity, high scores in design tasks, high levels of figural flexibility and the ability to engage in restructuring.

It could be argued that the measures previously applied within ITTE are subjective in nature, they are based on individual observations and don't capture the tacitness and implicitness of various levels of expertise during sketching activities (Suwa, 1998). In order to reinforce the previous findings (Lane, 2010c), it is considered necessary to apply a scientific tool to measure sketching behaviour and cognitive actions during design based sketching tasks.

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). Notable research methodologies that use visual and verbal protocol analysis during design based sketching activities have been described by both Suwa et al. (1998) and Middleton (2008).

Suwa et al. (1998) provide a detailed scheme to code the cognitive actions of designers during visual and verbal protocols where four major categories correspond to different levels of cognitive processing. Each major category is in turn broken down into subcategories with relations between actions such as dependencies and trigger relations. Subsequent to examining the scheme designed by Suwa et al. (1998), it was considered too complex to delineate and there appears to be limitations and lack of research within the scheme in relation to conceptual type actions (Suwa, 1998, p.468).

On the other hand, Middleton (2008) provides a detailed analysis of the application of visual and verbal protocol analysis to examine cognitive actions among design students 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 located 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 1. Note the very different types of problem solving strategies applied; where Subject A1 is perceived as a novice and Subject A3 is perceived as an expert. The expert engages in significant exploration in the beginning and once problem solving commenced the problem was largely resolved by tentile 4. A more detailed analysis of the research methodology applied by Middleton (2008) will be provided later in the paper.
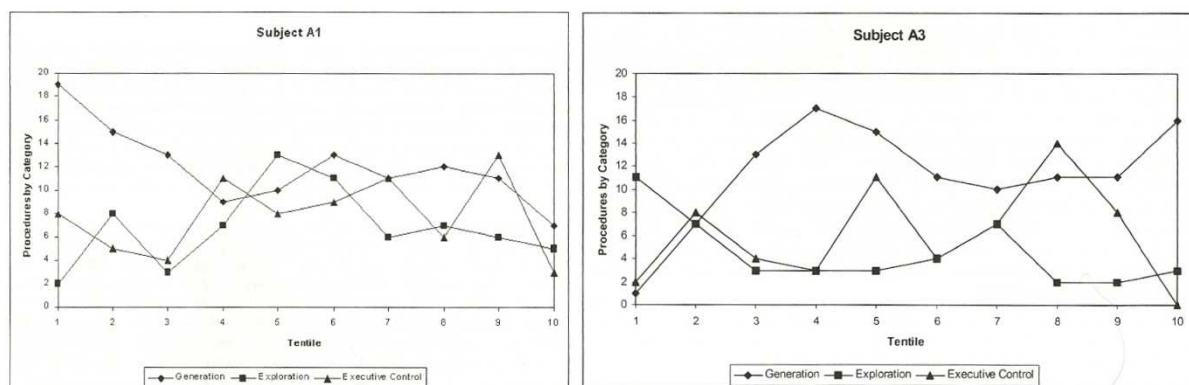

Figure 1 – Scatterplot showing cognitive procedures during a design based sketching task ((Middleton, 2008)

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 necessary model for establishing the pre-instruction sketching ability of students within ITTE.

Following this brief review of literature surrounding visual and verbal protocol analysis and the decision to base the research design around Middleton (2008), a description of the research participants and their selection will now be presented.

3. Research Participants

As previously outlined, the research described in this paper is an element of a larger research project (Figure 2) that is currently being carried out with 134 year three, undergraduate students through a Design and Communication Graphics module within the area of Initial Technology Teacher Education (ITTE). A core element of the module of study undertaken by the students is the development of their ability to communicate and problem solve graphically through freehand sketching. All students undertake a series of specially designed sketching based activities similar to those described by Lane et al. (2010b) over a three week period.
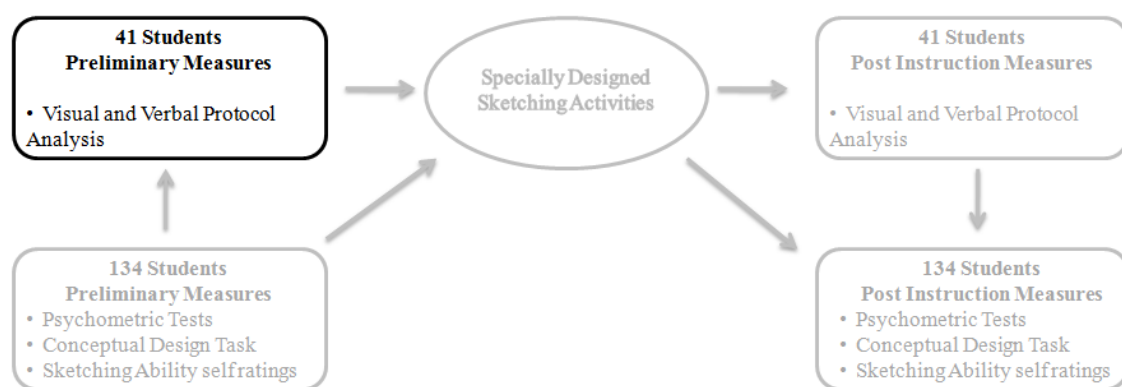

Figure 2 – Broad scale research methodology

Is should be made clear that this paper does not examine the activities that the students undertook. Rather, the paper details the application of visual and verbal protocol analysis to examine students sketching ability and behaviour before undertaking the specially designed activities (Figure 2). Prior to establishing the pre-instruction sketching behaviour of students it was decided that some preliminary data should be gathered.

Students were asked to rate their ability to freehand sketch along a five point Likert scale (Cohen et al, 2007) where 1=Very Poor…5=Very Good. This five point scale is comparable to the novice/expert categorisation developed by Dreyfus and Dreyfus (1986) which comprises of novice, advanced beginner, competent, proficient and expert. Students were also asked to state their experience in graphical education at second level, whether they studied graphics at Senior Cycle, Junior Cycle or none at all.

As the visual and verbal protocol analysis took place outside of normal hours, students were asked to volunteer. 41 students in total volunteered to take part in the visual/verbal protocols.

The relationship between the perceived level of expertise between the entire cohort (137 students) and the 41 volunteers was investigated using Spearman's Rank Order Correlation (rho). There was a large correlation between the two variables, $rho=.900$, $n=5$, $p < .05$. The mean level of perceived expertise was 2.37, which corresponds to the *"poor"* or *"advanced beginner"* (Dreyfus & Dreyfus, 1986) level.

The relationship between the two groups graphical experience at second level was investigated using Spearman's Rank Order Correlation (rho). There was a large correlation between the two groups, *rho*=.949, *n*=5, *p* < .05.

Based on the above correlations, it can be concluded that the group consisting of 41 volunteers is homogenous relative to the entire cohort[1]. This is illustrated graphically in Figure 3.
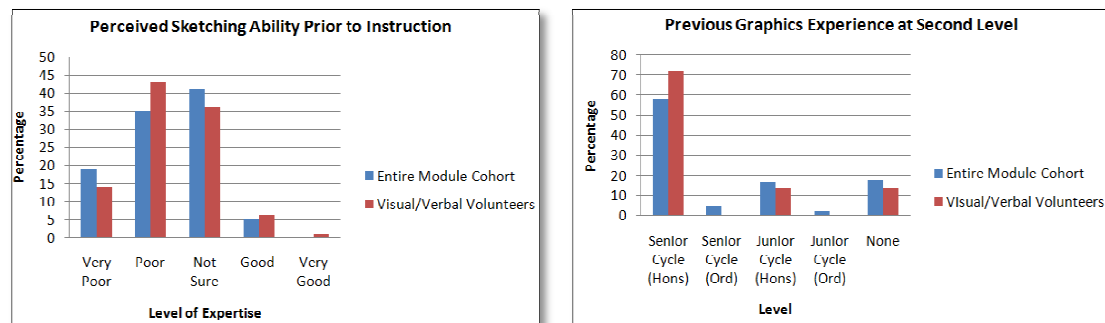

Figure 3 – Perceived sketching ability of participants prior to instruction

The next section of the paper describes the research environment and the task that was set for the students.

4. Research Environment

The research experiment was carried out in a classroom similar to that in which graphics and design activity usually occurred within the university. The protocols took place in the evening time outside of normal classroom hours. Students were scheduled to attend in groups of six for a thirty minute period.

Prior to informing the students of the design task, they were given formal instruction on verbal think-aloud protocols and they were informed that they would be consistently reminded to think-aloud during the problem solving task. Every student was given a headset to record their verbalisations and a webcam was positioned in front of them so that it only captured the drawing sheet and hand movements. The set-up of equipment can be seen in Figure 4.

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[1] Note, for clarity the other preliminary measures which include the psychometric tests and sketching based design task, are not considered within this paper.
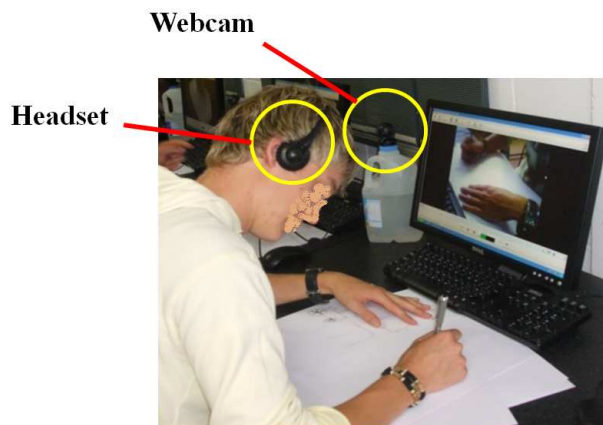
Figure 4 – Typical set-up of recording equipment during problem solving process

Sketching Based Task

The sketching based design problem 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 and the influence of the 2011 coursework design brief for Leaving Certificate Technology (State-Examinations-Commission, 2011), the following brief was devised:

> *"Boiling water is a task that people carry out regularly in daily life. Design an artefact that can be used to boil water. The artefact should be designed for somebody you hold in high regard and should be appealing to this person. The artefact should include some sort of a mechanical or electrical system."*

Students were allowed twenty minutes to complete the task and were regularly encouraged throughout to keep thinking aloud. Figure 5 depicts the environment during the problem solving process. At the end of the twenty minute time period, students were asked to stop sketching and give a brief thirty seconds of feedback in relation to the activity itself and their experience of visual/verbal protocols.

Figure 5 – Students sketching during visual/verbal protocols

The results of the visual/verbal protocols and the student experience will be presented in the next section.

5. Collecting the Data

Subsequent to collecting the visual and verbal protocol data, all of the videos were examined, the verbal data was inputted and coded and the relationships between the visual and verbal data was analysed. This method for analysing the data is illustrated in Figure 6.
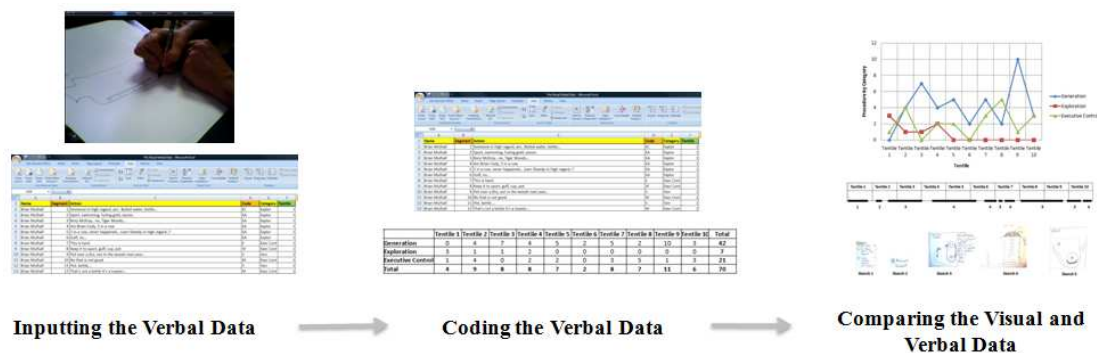

Inputting the Verbal Data   Coding the Verbal Data   Comparing the Visual and Verbal Data

Figure 6 – Method for analysing Visual and Verbal Data

As stated previously, the purpose of this paper is only to give an insight into the sketching behaviour of perceived *"advanced beginner"* (Dreyfus & Dreyfus, 1986) sketchers within ITTE. The protocols of one student will be presented in this section and the results section will detail the data of four students all of whom categorised themselves as having *"poor"* sketching ability.

Inputting the Verbal Data

The continuously recorded video tapes 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 was also monitored. This enabled a distinction to be made between sketching episodes and non-sketching episodes. Whenever the student was sketching while talking, it was decided that italicized segments would be inputted to allow for a clear distinction between sketching and non-sketching episodes (Figure 7).

Segment	Action
1	*Design brief... Has to boil water... Has to be for a person you admire... Person held in high regard*
2	*So that's two elements that I must integrate into my design*
3	*So the first thing to do is to decide on a person in high regard*
4	*It could be a family member, celebrity, educator, work employee*
5	Lot more pressure on me because I have to think of the design..
6	*Right, I'm going to choose my father as my person in high regard*
7	*Things that appeal to my father are gold associated*

Figure 7 – Inputting the verbal data

Coding the Verbal Data

Once all of the verbal data was 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 1.

Table 1 – Middleton's categorisation of cognitive procedures

Category of Procedure	Generation	Exploration	Executive Control
Procedure	Retrieval (R) Synthesis (S) Transformation (T)	Exploring Constraints (EC) Exploring Attributes (EA)	Goal Setting (GSet) Strategy Formulation (SF) Goal Switching (GSwit) Monitoring (M) Evaluation (E)

The terms for each of the procedures should be self explanatory but a comprehensive description is given in Middleton (2008, p.197-198). One person coded all the segments in order to maintain internal reliability throughout the study. Where there was uncertainty surrounding the coding of some verbal data, the visual data was examined carefully to determine a better insight into the nature of the cognitive action. Examples of the applied coding scheme are shown in Figure 8.

Segment	Action	Code	Category
1	*Design brief... Has to boil water... Has to be for a person you admire... Person held in high regard*	EC	Exp
2	*So that's two elements that I must integrate into my design*	EC	Exp
3	*So the first thing to do is to decide on a person in high regard*	GSet	Exec Cont
4	*It could be a family member, celebrity, educator, work employee*	FA	Exp
5	Lot more pressure on me because I have to think of the design..	E	Exec Cont

Figure 8 – Example of the coded cognitive actions

Comparing the Visual and Verbal Data

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. (1998), 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.

When all the data was broken into tentiles, it enabled the creation of a scatterplot that illustrates the amount of cognitive actions and their corresponding categories for the entire sketching episode. An example of the type of scatterplot and corresponding table is shown in Figure 9.

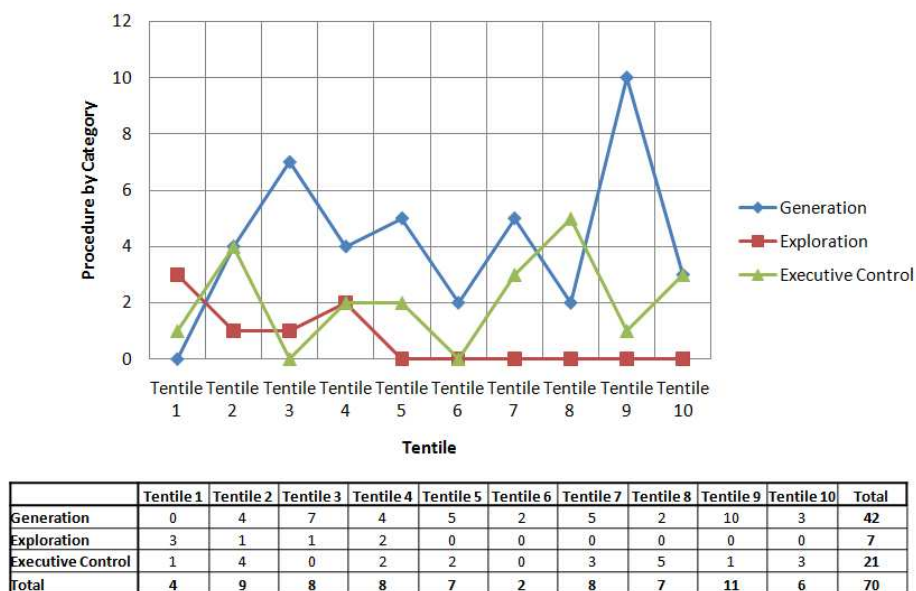|	Tentile 1	Tentile 2	Tentile 3	Tentile 4	Tentile 5	Tentile 6	Tentile 7	Tentile 8	Tentile 9	Tentile 10	Total
Generation	0	4	7	4	5	2	5	2	10	3	42
Exploration	3	1	1	2	0	0	0	0	0	0	7
Executive Control	1	4	0	2	2	0	3	5	1	3	21
Total	4	9	8	8	7	2	8	7	11	6	70

Figure 9 – Typical scatterplot generated using the verbal data

In order to further comprehend each students sketching behaviour during the task, the visual data was carefully examined to establish how many sketching episodes took place and the specific time for each. The data presented in Figure 10 illustrates the length of each sketching episode and the corresponding sketch. Note, the bold black lines along the tentile breakdown indicates that sketching is taking place and the number underneath corresponds to the sketch number.
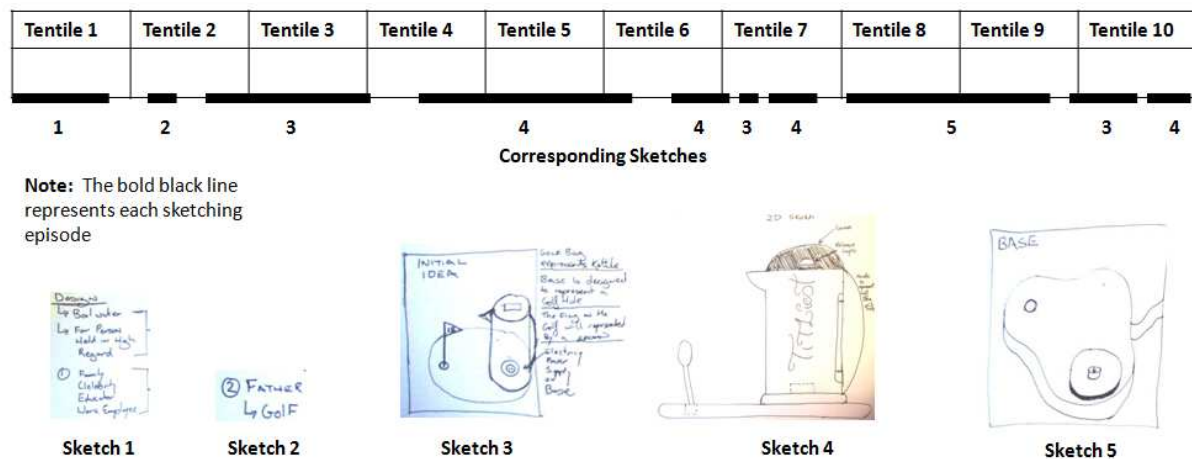
Tentile 1	Tentile 2	Tentile 3	Tentile 4	Tentile 5	Tentile 6	Tentile 7	Tentile 8	Tentile 9	Tentile 10

Corresponding Sketches

Note: The bold black line represents each sketching episode

Sketch 1   Sketch 2   Sketch 3   Sketch 4   Sketch 5

Figure 10 – Identifying each sketching episode and the corresponding sketch

It should be noted that Middleton (2008) further explores the visual and verbal data by examining the initiation of image production and the relationships between cognitive procedures and visual mental imagery usage. However, the research within this paper does not extend to this. The next section will explore the data gathered based on the method described.

6. Results

The data presented in this section is based on the visual and verbal protocols of four students who represent the majority of students that rated their pre-instruction sketching ability as *"poor"* or *"advanced beginner"*. The scatterplots illustrated in Figure 11 describe the cognitive procedures for the students over the duration of the sketching task. There doesn't appear to be any consistencies between the scatterplots although the relatively low levels of exploration are notable and will be discussed later in the paper.
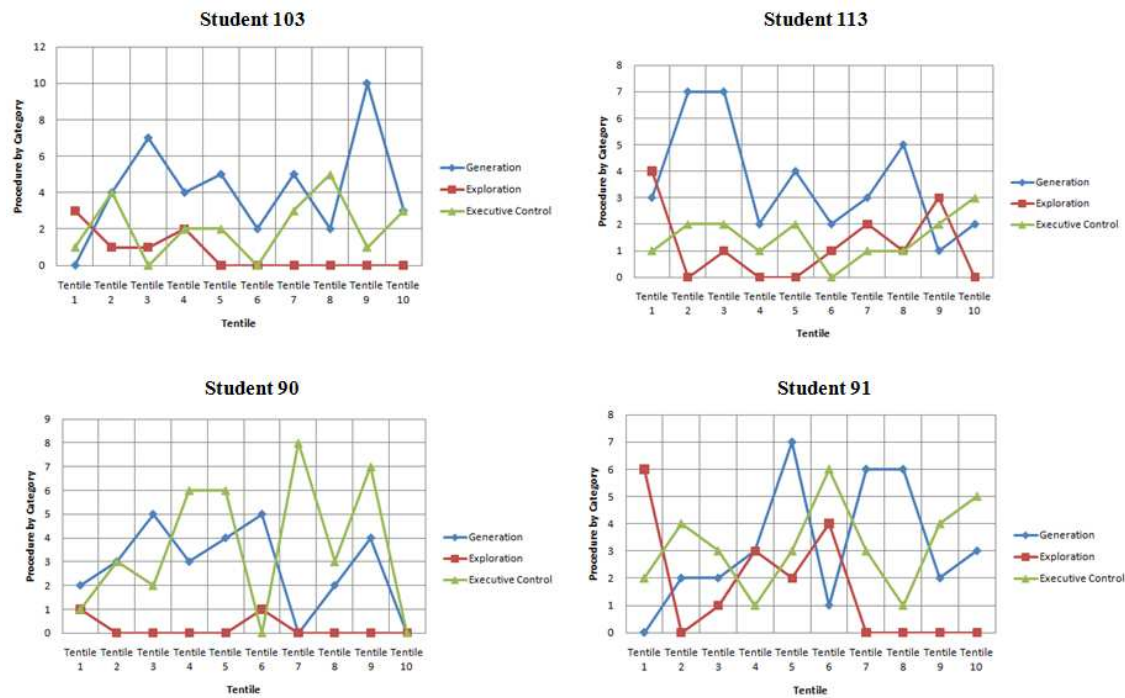
Figure 11 – Cognitive actions of students during the sketching based design activity

The data in Figure 12 depicts the visual protocols for each student and includes each sketch and its corresponding time along the different tentiles. This rich source of data enables significant analysis of the type and number of sketches that the students produced and the length of time spent during each sketching episode.
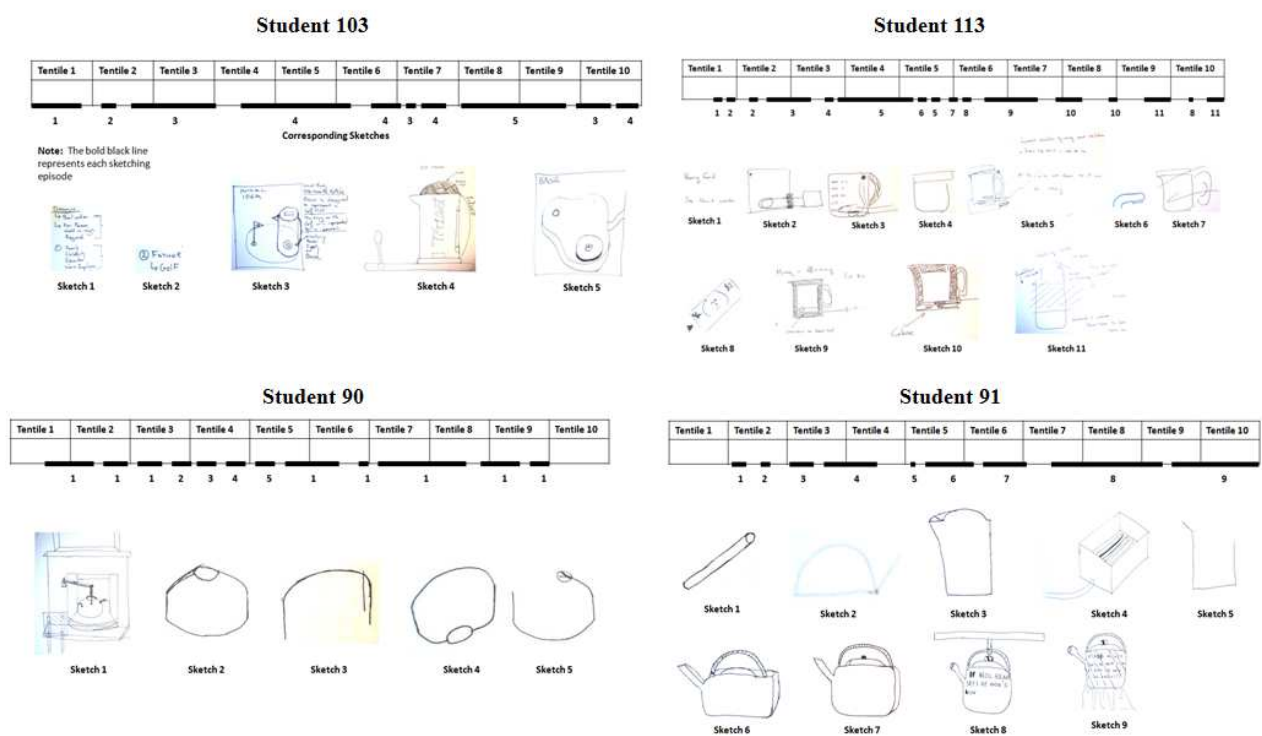

Figure 12 – Breakdown of sketching episodes and visual data

Subsequent to completing the visual and verbal protocols, all 41 students were asked to give feedback on their performance during the activity and to give their opinion on their experience during the think-aloud verbal protocols. The data gathered from this feedback is illustrated in Figure 13.
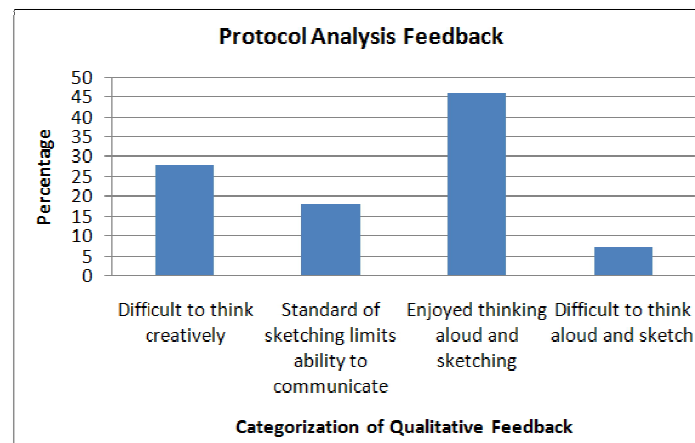

Figure 13 – Qualitative Feedback Subsequent to the Activity

Typical feedback from students was predominantly positive. A typical positive and negative comment is shown below.

"This was very interesting; talking while you're designing keeps your thoughts going towards to what you actually want to do… If you keep your thoughts in your head, you just get stuck with the one idea…" - Student 51 (Positive)

"I don't really feel right or comfortable drawing this way… … Id rather have a purpose behind what I draw and know what I'm drawing… rather than just making it up as I go along… 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…" – Student 137 (Negative)

7. Discussion

Given the richness of the gathered data and the results presented so far, it is considered appropriate to limit the discussion around the scatterplots of student's cognitive actions presented in Figure 11 and link the results of these to the relevant literature. Firstly, each student's graph will be discussed in relation to Middleton's (2008) expert. A decision will then be made as to whether the trends are similar or dissimilar.
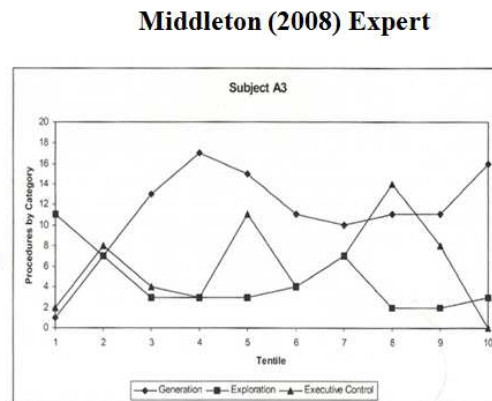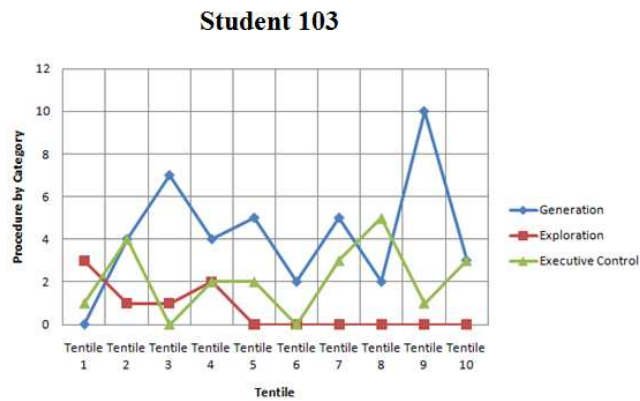
Figure 14 – Analysing Student 103 in relation to Middleton's (2008) Expert

Analysis of the graph (Figure 14) of Student 103 in relation to Middleton's expert reveals the following:

- **Generation:** The generation line for Student 103 is somewhat similar to that of the expert with a general increase in generation actions as the task progressed. **Verdict:** Similar
- **Exploration:** Student 103 appears to have engaged in exploration only in the beginning and ends after tentile 4. In contrast, the expert maintains a level of exploration throughout. **Verdict:** Dissimilar
- **Executive Control:** The levels of executive control for Student 103 appear to increase and decrease throughout the task and this appears to be the same as the expert. **Verdict:** Similar
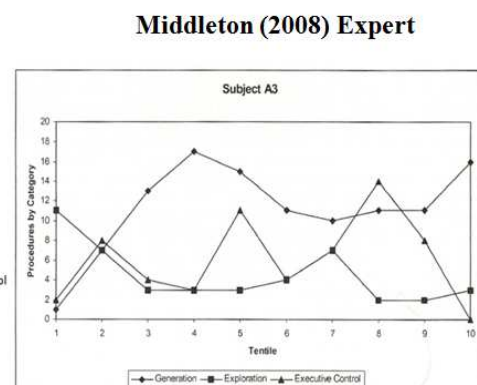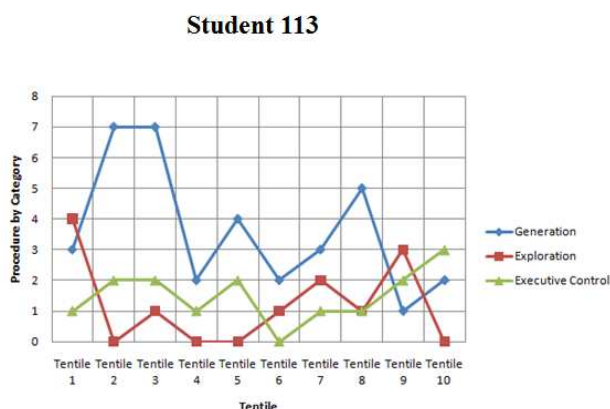

Figure 15 - Analysing Student 113 in relation to Middleton's (2008) Expert

Analysis of the graph (Figure 15) of Student 113 in relation to Middleton's expert reveals the following:

- **Generation:** The generation line for Student 113 is almost inversely proportional to that of the expert with high levels of generation at the beginning and decreasing as the task progressed. **Verdict:** Dissimilar
- **Exploration:** Student 113 appears to have engaged in somewhat similar levels of exploration as the expert with high levels at the beginning and fluctuating as the task progressed. **Verdict:** Similar
- **Executive Control:** The levels of executive control for Student 113 appear to increase and decrease throughout the task and this appears to be the same as the expert. **Verdict:** Similar
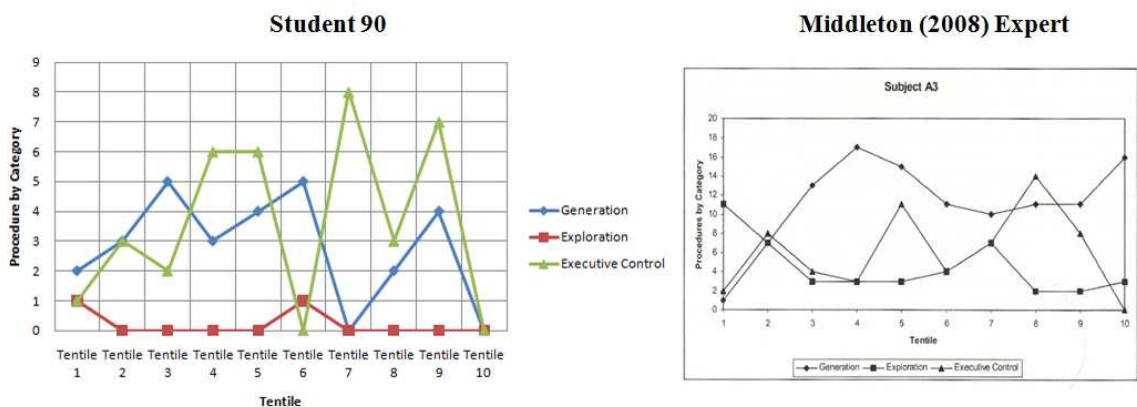

Figure 16 - Analysing Student 90 in relation to Middleton's (2008) Expert

Analysis of the graph (Figure 16) of Student 90 in relation to Middleton's expert reveals the following:

- **Generation:** The generation line for Student 90 appears somewhat similar but there is an obvious decline in generating actions at tentile 7 corresponding to high levels of executive control. **Verdict:** Similar
- **Exploration:** Student 90 doesn't appear to have engaged in any meaningful level of exploration throughout the whole activity which is in contrast to the expert. **Verdict:** Dissimilar
- **Executive Control:** The levels of executive control for Student 90 appear to increase and decrease throughout the task and this appears to be consistent with the expert. **Verdict:** Similar
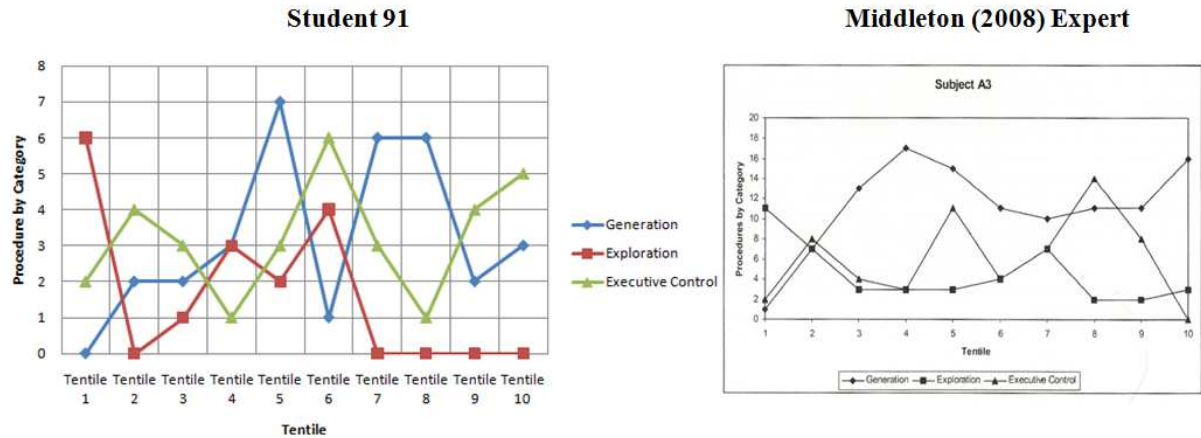
Figure 17 - Analysing Student 91 in relation to Middleton's (2008) Expert

Analysis of the graph (Figure 17) of Student 91 in relation to Middleton's expert reveals the following:

- **Generation:** The generation line for Student 91 is somewhat similar to that of the expert with a general increase in generation actions as the task progressed. **Verdict: Similar**
- **Exploration:** Student 91 appears to have engaged in significant exploration at the beginning and had no exploring actions in tentile 2. Exploration resumed again in tentile 3 and continued until tentile 7 where exploration totally stopped. **Verdict:** Dissimilar
- **Executive Control:** The levels of executive control for Student 91 appear to increase and decrease throughout the task and this appears to be the same as the expert. **Verdict:** Similar

Based on the above comparisons of the different students cognitive actions and those of Middleton's (2008) expert, it can be concluded that none of the students are behaving like an expert. However, it should be noted that collectively the four students have all the attributes that Middleton (2008) claims experts portray during sketching based design activities.

It can be hypothesised that based on the initial findings presented within this paper, that once the novice sketchers develop the attributes to use freehand sketching as a *"sense-making supporting tool"* (Lane et al., 2010b, p.71) they will grow towards a level of expertise. Taking other literature into consideration, it is anticipated that as students develop the necessary cognitive and psychomotor skills that they will increase their number of cognitive actions (Kavakli et al., 1999) as well as their ability to explore and restructure (Verstijnen, 1998) concepts during sketching tasks.

The data presented within Figure 13 should also be taken into consideration. It is notable that around 18% of students felt that their perceived poor standard of sketching limited their

ability to communicate conceptually. This may also be an influencing factor as to why novice sketchers do not engage in significant periods of exploration during sketching tasks.

8. Conclusion

The aim of this paper was to scientifically establish the sketching behaviour of perceived novice sketchers within Initial Technology Teacher Education prior to undertaking specifically designed sketching based tasks. The application of Middleton's visual and verbal protocol analysis model (2008) provided significant indications as to what attributes require development in order to reach a level of expertise in freehand sketching. It was found that the novice sketchers within ITTE do not engage in sufficient levels of exploration during sketching activities and this may be contributing to *"functional fixedness"* (Adamson, 1952).

It is believed that the strength of the larger research project that is being carried out within the confines of Initial Technology Teacher Education (ITTE) lies within the novel design of a paradigm for developing expertise in freehand sketching and the application of several metrics to determine the magnitude of any development. The application of Middleton's visual and verbal protocol analysis scheme provides a robust scientific measure to capture the tacitness and implicitness of the complex cognitive actions evident during sketching activities. It is anticipated that the results of the study will inform the future progression of pedagogical models within graphical education.

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