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Message from the Chair: Current and Relevant

Timothy Sexton
Ohio University

In graphics our goal is clear; help students learn to visualize so they can ideate with themselves, communicate graphically with others, and communicate according to industrial standards. How we reach these goals is ever changing. In my thirty-four years of teaching graphics the most significant change in the curriculum has been the introduction of 3-D modeling. It has fundamentally changed the way students learn to visualize. But even with this fundamental change my preferred method of teaching graphics has not changed. The only way to learn graphics is to draw and/or model. My teaching philosophy reflects this principle. I call it my “Sink AND Swim” principle of teaching graphics. In a graphics course students do not want to listen to you talk about drawing – they want to do it! I believe students learn and retain graphic principles best when they are allowed to struggle with a problem on their own. After giving students the minimal amount of information to get started, I like to use my three favorite words in teaching “go to work”. This gives me the opportunity to become more of a coach and help students with their struggle. When they begin to sink we can reconvene and talk through the problem a little more. Then the process repeats itself until the task is completed. Ideally I prefer to have all my lecture/lab time entirely in the lab so I can give mini lectures when they are needed.

In order to help students as they struggle, we must keep ourselves current and relevant. With 3-D modeling as the tool of choice, it is a challenge to keep up with the ever present changes in the software. At times the problem is not keeping ahead of students it is keeping up with them.

Speaking of keeping current and relevant, changes in our division have taken place this past year through the leadership of some of our members. Our EDG journal editor Bob Chin continues to oversee the new challenges with transitioning our EDG journal into its online format. Our director of membership Kevin Devine has reported that our current membership is two hundred and fifty strong with four new members. Four may not appear to be a lot but this type of growth will keep our division strong for years to come especially if they become active members. Our vice chair Aaron Clark has provided us with the idea to combine the three executive committee directorships of liaison, professional and technical, and zones into the more current and relevant director of communications. This change will become official when we vote on new by-laws.

Two new executive members have been elected. Nancy Study was elected vice chair and Nick Bertozzi was elected director of communications. Both have proven leadership records in the division and we are leaving these two positions in good hands.

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Thanks to the remaining executive committee members: Sheryl Sorby director of zones, Norma Veurink secretary-treasurer, and a special thanks to our vice chair Aaron Clark for stepping in for me when I took ill and had to leave the midyear early.

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Message from the Editor: New Look

Robert A. Chin
East Carolina University

As the ASEE annual proceedings and the EDGD mid-year proceedings have gone—to a single column format—so too have the pages of the *EDGJ*. We hope you like it.

The intent was to make it easier for those who read from the screen and for those who want to—keeps us from having to scroll up and down. Once we get reactions from the readership and respond to their concerns, we will roll out an author template, which will be housed on the *EDGJ* site. This should ease the submission, review, and publication process.

Publication of the *EDGJ* will still be guided by the current edition of the *Publication Manual of the American Psychological Association* (APA). Currently it is in its sixth edition. If you don't have a copy of the APA style manual, guidance is available online at, among other locations, http://owl.english.purdue.edu/owl/section/2/10/ The site provides examples for the general format of APA research papers, in-text citations, endnotes/footnotes, and the reference page. It is not a substitute for the manual itself however.

From time to time, we will offer suggestions to those new to the APA style manual in this column. The suggestions will be based on input from the journal's referees and the readership. In this editorial, we'll look at table construction, artwork, and artwork resolution.

One of the differences between the APA style manual and others is in the construction of tables. APA asks authors to prepare their tables with (a) minimal rulings—ie no cells or excessive ruling, (b) no bold or italicized text unless bolding is really essential, and (c) no fill.

All illustrations, figures, and tables are to be placed within the text at the appropriate points, rather than at the end. Once the manuscript is accepted for publication, all electronic artwork supplied by the author shall have a resolution of between 300-600 dots per inch. If it is much less, the quality of the article will be compromised.

We look forward to your submission and are available to assist if you have questions or concerns about your submission.

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The Chair's Award

The 2010 Chairs Award winners are Diarmaid Lane and Niall Seery of the University of Limerick for their paper, Freehand Sketching as a Catalyst for Developing Concept Driven Competencies.

The Chair's Award recognizes the outstanding paper presented at an EDGD sponsored ASEE Annual Conference session and carries a cash award. Their paper appears on the following pages and can be downloaded from http://search.asee.org/search/fetch;jsessionid=bkgmio2mc73j3?url=file%3A%2F%2Flocalhost%2FE%3A%2Fsearch%2Fconference%2F32%2FAC%25202010Full1212.pdf&index=conference_papers&space=129746797203605791716676178&type=application%2Fpdf&charset=

The award description can be found at http://edgd.asee.org/awards/chairs/index.htm

The past awardees list can be found at http://edgd.asee.org/awards/chairs/awardees.htm

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AC 2010-1212: FREEHAND SKETCHING AS A CATALYST FOR DEVELOPING CONCEPT DRIVEN COMPETENCIES

Diarmaid Lane, University of Limerick

Niall Seery, University of Limerick

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Freehand sketching as a catalyst for developing concept driven competencies

Abstract

At a time when concept driven competencies are perceived to be critical in redefining effective technological education, the introduction of Design and Communication Graphics at senior cycle in Irish 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. As a result, freehand sketching has become an integral facet of all technological subjects.

Action research currently being carried out at the University of Limerick aims to identify a sustainable intervention strategy for the development of concept driven competencies in students of technological education. Core to this is the development of student's ability to freehand sketch what is both perceived and conceptualised.

This paper presents findings of an intervention strategy carried out with a cohort of 124 pre-service teachers of technology education. The study develops participant's ability to engage in higher order symphonic cognition as well as the harmonisation of fundamental communication skills through the medium of freehand sketching.

The approach for the research followed a five phase intervention strategy. An initial pre-instruction covariant exercise was used to measure participants overall communication ability together with their capacity to engage in higher order thinking. Stage one, two and three developed the aptitudes of recognition, enquiry and synthesis through the use of both regular and non-regular geometry embedded in dual purpose activities. Stage four, moving towards conceptualisation, employed a comparative photographic composition as a measure of students previously perceived composition. The final stage centred on an organic composition derived by the students that outlined their ability not only to communicate but also present symphonic aptitudes.

The key findings for this paper are significant in terms of developing a sustainable strategy for teaching freehand sketching in Irish high schools. Instantaneous improvement resulted in participants developing an intrinsic motivation to develop their skills and engage in the activities as autonomous learners. An innovative pedagogical strategy was applied. This facilitated a cohort of thirty participants and incorporated *Pareto's Law* and the *80/20 Principle*. The concept of realising and developing personal styles in the communication of compositions was a novel finding of the research. Relationships between *metacognition* and sketching competencies are discussed with implications for the exploration and development of complex solutions in plane and descriptive geometry.

The paper concludes by highlighting the value of freehand sketching in developing symphonic design capabilities, the implications of this skill in terms of transferability and access of the *physical symbol system* present in the cognitive architecture.

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Introduction

The purpose of this study was to further develop and investigate the effectiveness of an intervention strategy which aims to determine how freehand drawing can be applied as a multi-purpose autonomous learning tool in technology subjects in the Irish education system [1].

Previous research carried out at University of Limerick with a cohort of nine participants established that sketching is a teachable skill that can be learned by the majority of people, irrespective of innate ability. It was also evident that the holistic value of learning to sketch using a defined process was far greater than the completed composition. Increased levels of enquiry, recognition of patterns and synthesis between unrelated elements in compositions provided an indicator that there is an underlying cognitive value to this activity which requires further investigation [1]

In order to further develop this previous research, the intervention strategy will now be analysed in terms of developing a pedagogy that will facilitate class sizes up to thirty participants and incorporate the paradigm of *"diminished return"*. In addition to this the transferability of freehand drawing as a critical tool in developing concept driven competencies as well as solving problems in plane and descriptive geometry will be explored.

Teaching and Learning

Deficiencies in engineering education have been exhaustively enumerated in recent years with experts advising educationalists in several areas such as the exploration of real world engineering designs and the development of critical and creative thinking and problem solving skills [2]. In response to this, the development of new and improved methods of teaching and learning has become a universal aim among technological teachers over the past ten years [3]. The introduction of a new suite of technology subjects at senior cycle in the Irish education system has brought about an unprecedented need for a change in pedagogic structures. Fundamental to all of the technological subjects is the development of technological capabilities. Design and Communication graphics has particular importance in developing students ability to *"apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity"* through design and realisation [4].

Craft subjects traditionally derived their educational justification from their contribution to the emotional and physical development of children in preparation for work. Refined curriculum in technology education throughout the world has incorporated a design element that is becoming increasingly recognised for developing intellectual skills in students [5]. As design is a demanding and complex problem solving activity of great economic and social importance, sketching has an integral part to play [6] and a defined pedagogic approach is important to ensure the required abilities are nurtured [1].

In the Irish second level system, teachers are required to facilitate the learning of students who are in one of two possible phases of cognitive development; concrete operational stage or formal operational stage [7]. It is important that teachers recognise

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what stage of development students are at and structure their lessons at a level that is consistent with or slightly advanced than the students existing schemes. This will facilitate the nurtured process of cognitive growth [8].

Previous research in freehand drawing carried out at University of Limerick found that participants engaged in *"increased levels of enquiry, recognition of patterns and synthesis between unrelated elements"* while constructing various compositions [1]. These increased levels of *"cognitive engagement"* [9] suggest that the participants had developed an *"intrinsic motivation"* [8] to become competent and assimilated different schemes to engage in *"hypothetico-deductive reasoning"* [10]. As a result it can be hypothesised that the participants reached the upper levels of Blooms Taxonomy of Educational Objectives; Analysis, Synthesis and Evaluation [11].

Current research aims to establish how a class size of thirty students can reach the same level of *"cognitive engagement"* and achieve higher results than the original participant group of nine people. Previous testing carried out took fifteen hours to complete [1] but due to timetabling restrictions this will need to be reduced to an eight hour period. The present challenge is to facilitate the cognitive development of these large class groups so that the *"Zone of Proximal Development"* [12] is identified which will in turn enable participants to enter the *"symbolic mode"* [13] of development which leads to *"formal operational cognition"*[7].

In response to the logistical restrictions placed on this study in terms of classroom delivery time and increased participant numbers it is worth analysing *"Pareto's Law"*, which is also known as the 80/20 principle [14]. This principle based on the paradigm of *diminished return* has been successfully applied in language courses by Michel Thomas where it was found that the most effective way to teach was to find out what would be most useful to students new to a subject area. Figure 1 illustrates how eighty percent of results would flow from twenty percent effort in a system [15].

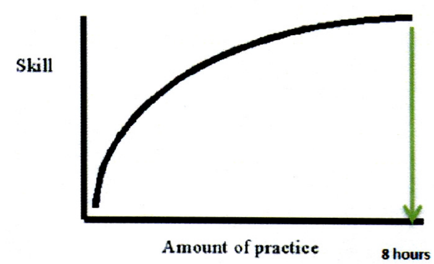

Figure 1 – Illustrating 80/20 Principle

In conjunction with *Pareto's Law* it is important to value the student's ability to think independently and form hypotheses. The time spent on teaching information should be reduced in order to focus on the direct teaching of higher order thinking and the development of *"operacy"* (which is the ability to do things and make things happen)[16]. It can therefore be hypothesised that by coupling *Pareto's Law* and de Bono's view of direct teaching of thinking, a defined structure for facilitating freehand sketching can be established. Twenty percent of classroom time will be spent teaching core principles outlined in the previous study [1] which are critical to learning how to freehand draw. The remaining eighty percent of participant's time will be spent engaging in critical thought integrated with incubation periods that will help dissipate *"functional fixedness"* [17].

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Concept Driven Competencies

The development of cognitive and psychomotor skills in communication graphics, problem solving and critical thinking is a primary aim of Design and Communication Graphics in the Irish second level system. In addition to this, students are provided with an appropriate learning environment where they can plan, organise and present creative design solutions using a variety of skills, techniques and media [4]. Assessment of the subject is in two components: A design assignment (worth forty percent of marks) that assesses students on elements that cannot be readily assessed through the terminal examination that is worth sixty percent of marks.

Core to both components is the development of *"Concept Driven Competencies"*, where students are expected to develop an ability to engage in *"metacognition"*[18] where principles and problems are analysed, solutions are formulated and effects of these are evaluated taking into consideration one's strengths and weaknesses. This in turn, helps develop abilities to problem solve, creatively design, communicate ideas through freehand sketching and apply principles of plane and descriptive geometry to various problems[4].

The philosophy of Design and Communication Graphics promotes creative thinking, discovery and personal decision making and it is clear that these principles are related to design education in all subjects and not just art education [19]. The realisation of this philosophy will see students having a *"high concept"* aptitude of *"symphonic thinking"* which is critical for economies to succeed in the *"Conceptual Age"* [20]. Teaching methods must ensure that students are able to synthesise their abilities to enquire, explore, communicate, manipulate and evaluate information [5].

In relation to freehand drawing, it has been found that a variety of intellectual skills can be systematically developed in order to draw well. The ability to recognise, enquire and synthesise information [1] should be integrated into McKim's model of visual thinking (figure 2) *"when seeing, imagining and drawing merge into active interplay"* [21]. This interplay could involve regular/irregular geometric problems or complex design problems all of which require *symphonic* and *concept driven* competencies.

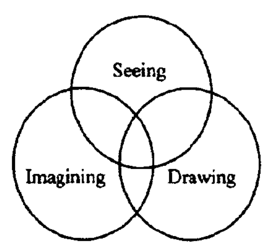

Figure 2 – McKim's model of visual thinking

Cognitive Architecture

The human mind is a remarkable information-processing system that is astonishingly powerful in most instances and yet surprisingly limited in others [22]. 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) [23]. Cognitive psychology concerns human cognition. The capacity to perceive, memorise, think, learn and engage in problem solving is misconceptualised among teachers and educational specialists [22, 24]. In this section an initial overview of the cognitive architecture will be given in order to provide an insight into how students process information.

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Given the broad level of abilities that teachers of technological subjects are faced with, it is important to have an understanding of human cognitive potential, its information processing capacities and mechanisms. Human beings receive information through their senses, engage in some form of thought about that information and carry physical action through voluntary muscular movement. Central to the human cognitive architecture 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 [22].

The transfer of physical energy impinging on the human body and conversion into electrochemical activity through special nerve cells called receptors is known as *transduction*. Sensory systems including vision, hearing, taste, smell and touch have complex architectures to complete this initial transduction and further processing of sensory input [22]. Sensory systems are *"informationally encapsulated"* and their ability to classify and process inputs is evidence of the *"modularity thesis"*. That is, a sensory system transforms a class of environmental inputs into outputs that can be used by the central systems [25].

Thinking is a key component of the central system of cognitive architecture. The ability to think is an amazingly flexible, limitless cognitive tool which enables a person to draw conclusions, make plans and solve problems in remarkably diverse domains in everyday life. Thinking can usually be characterised by a focus of attention, inputs from memory and our capacity to learn. Knowledge that is built up in human memory and both cognitive and motor skills are acquired over a life time. Integral to the central system is a *physical symbol system* [26] that contains a set of *"built-in information processing facilities"* that have the potential to acquire an unlimited range of further processes resulting in semantic interpretations of different environments [22]. Evidence of this physical symbol system and its programmable like potential must question the theories of experts in teaching freehand drawing where students are encouraged to use *"right hemisphere"* visual attributes to reduce the influence of the symbolic *"left hemisphere"* [27].

The ability of the cognitive architecture to retrieve information through *"distal access"* [26] of the symbol system, where the processing of one symbol evokes further processing of other symbolic structures, is significant in terms of teaching and learning in technology education. The construction of a mechanism or pedagogic structure to help students maintain, access and transform symbolic structures that are not immediately driven by sensory input or motor output has significant implications and has the potential to transform teaching and learning in areas such as design, problem solving and communication graphics.

Methodology

The approach for this research project involved a five phase intervention strategy which had a participant group of 124 pre-service teachers of technology education at University of Limerick. The participants are studying to teach subjects such as Engineering Design Graphics and Technology to high school students between the

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ages of twelve and eighteen. The research aimed to further investigate a previous study where freehand sketching was taught to a novice group of participants [1]. The creation of a learning environment and pedagogical mechanism to teach large group sizes of 30 participants in a restricted eight hour time frame was the underlying challenge.

Participants

The participant group consisted of 124 pre-service teachers of which 98.4% were male and the remaining 1.6% female. Figure 3 gives a breakdown of how many participants studied Communication Graphics at second level (high school level) and the level which was studied.

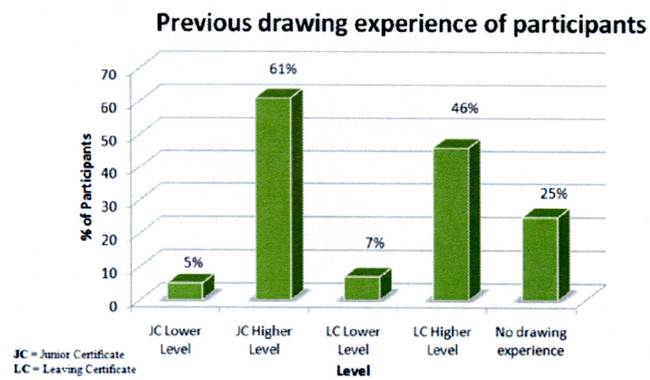

Figure 3 – Previous drawing experience of participants

All participants were required to take part in the activity which was run as an element of an Engineering Design Graphics module specifically for trainee teachers. The study was carried out over a four week period when participants attended classroom sessions for two hours per week. Class times were varied on different days and times throughout the week. Participants rated their own sketching ability prior to taking part in the research with a notable 57% of the group rating themselves as either *poor* or *very poor* (Figure 4).

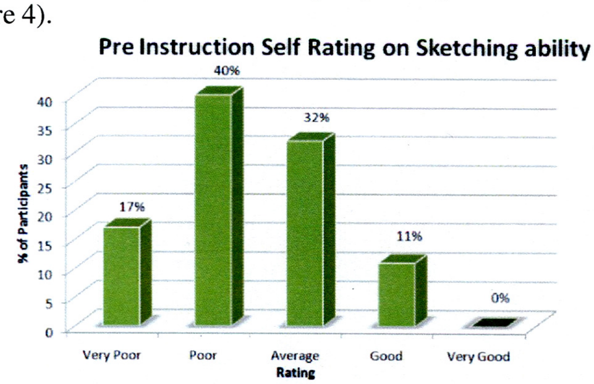

Figure 4 – Participant pre-instruction self rating on sketching ability

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Design Procedure

The strategy was broken into five stages which were all unique, yet complementary activities that had specific learning outcomes. The activities were strategically devised to develop critical cognitive attributes in the participants using a pedagogic structure that facilitated the independent exploration of learning. Instruction was given in a restricted timeframe of eight hours with appropriate incubation periods of one week.

Pre-Instruction Activity

In order to determine whether participant's ability to sketch improved throughout the study, it was necessary to have a pre-instruction activity. This acted as a covariant in relation to the final composition at the end of the study. Participants were given a 45 minute timeframe to draw their self portrait. A mirror, felt pens, pencils and erasers were provided and participants were given no limits in what they communicated.

Stage 1 – Recognition

Previous research carried out (Lane & Seery, 2009) has shown that when students are given an inverted drawing of irregular geometry, it can be drawn accurately by analysing and communicating the geometries when placed beside the original composition (Figure 5).

Figure 5 – Perception proof Exercise (Lane & Seery, 2009)

Analysis of the above approach resulted in an improved method being devised that will enable participants to develop additional attributes and this has implications for teaching large class sizes.

The revised approach for the recognition exercise involved 124 participants completing a composition which consisted of both regular and irregular geometries in a lecture theatre during a twenty minute time period. Rather than drawing an original composition at a scale of 1:1 (figure 5) and having the original directly alongside each participant, it was decided to present a composition on a screen measuring 4 meters across and 3 meters down.

Each participant was given a blank A4 sheet which consisted of an equally spaced grid of twenty four squares. Using a data projector and a PowerPoint presentation

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each grid of the composition was revealed with set time intervals (Figure 6). Participants were required to analyse the geometry in each grid and communicate this on their own sheet.

The following learning outcomes were critical to this activity:

- The ability to perceive and recognise the different geometries
- The ability to scale what was perceived on the large screen on to an A4 sheet
- The ability to realise the relationships between different geometries within each square and between different squares

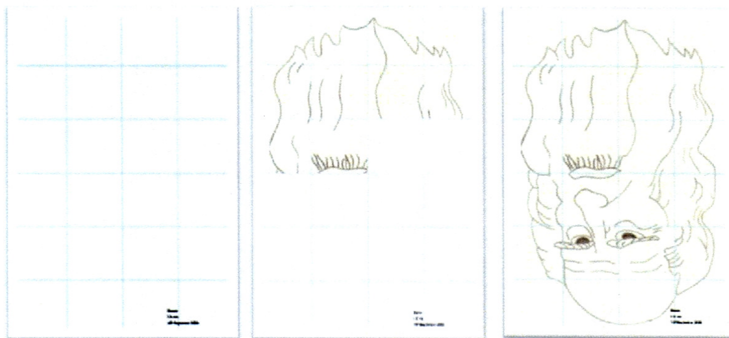

Figure 6 - Illustration of slides from PowerPoint presentation used for perception proof exercise

Stage 2 – Enquiry

A perception enhancement exercise was used to develop participant's ability to graphically represent a 3D composition on a 2D picture plane. Previous research found that the use of a floating picture plane which had to be balanced on the composition being communicated proved difficult for participants and was a source of unnecessary anxiety [1]. This needed to be addressed as the physical manipulation of the picture plane should be carried out quickly and without any difficulty in a classroom of thirty students. The picture plane shown in figure 7 was designed to address the previous issues. It is a standalone device which can be assembled and disassembled quickly by students of all ages and can be manufactured easily in most engineering rooms.

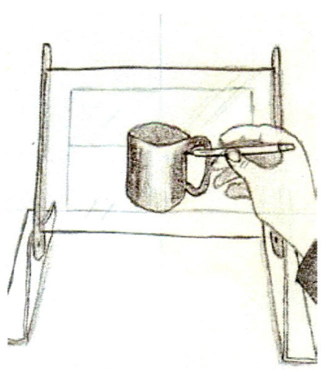

Figure 7 - Drawing on the picture plane

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In order to help develop *"design thinking"* [28] and autonomy in participants, it was decided that a brief was given that required the creation of a unique and imaginative composition that included the participants' hand and any other material they wished.

The following learning outcomes are integral to this activity:

- The ability to utilise previously developed skills from the perception proof exercise
- The ability to compose a physical composition that is creative and intrinsically motivating to draw
- The ability to draw accurately in perspective and understand the principles of the picture plane in relation to its position and the position of the spectator
- The ability to analyse a composition in detail to realise the intricate geometries and values that determine the *gestalt* in the completed drawing
- The ability to evaluate the sketched composition and make changes to help further improve

Stage 3 – Transfer

It was found previously that the ability to recognise different values in a composition and represent these on paper was a difficult concept to understand and carry out [1]. The current research project aimed to overcome this problem by engaging participants in a *Merging* activity that harnessed the skills that were developed in the previous two activities and developed new abilities to recognise and communicate different values in a composition along with the skill of sighting.

Selection of the composition that the participants would sketch required careful thought. It needed to contain both regular and irregular geometry, have a variance in the values that were represented, be interesting and related to technology education, be applicable to a learning environment of thirty participants and possible to complete in a thirty minute timeframe.

The composition shown in figure 8 was used for this activity. It was felt that this particular drawing satisfied all the requirements stated in the previous paragraph. In the context of teaching a large class size this exercise is deemed suitable for the following reasons:

- The composition can be shown to the whole class using a data projector and screen
- The concept of physically sighting the composition can easily be explained through a step by step instruction from any location in the room
- It is possible to question participants on key areas such as proportionality and relationships between geometries as well as different values in the composition because everybody is looking at the same screen

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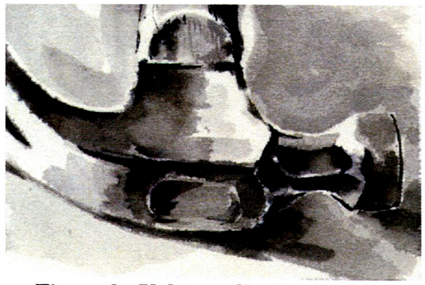

Figure 8 - Value realisation activity

The following learning outcomes are critical to the *merging activity*:

- The ability to analyse the composition and select a suitable piece of geometry which will act as a basic unit
- The ability to determine the overall size of the participants own composition by selecting a suitable scale for the basic unit
- The ability to apply the sighting technique to determine the relationships between the geometries within the composition. **Note:** The technique is applied using an extended straight arm and pencil as a measurement tool. By extending the arm at a set distance the participants are autonomously creating an imaginary picture plane which all geometries are projected to
- The ability to communicate the geometry using a pencil and eraser
- The ability to evaluate the sketched composition and make any alterations (as in previous activities)
- The ability to understand how the picture plane has now become abstract and imaginary
- The ability to determine the most suitable position for the imaginary picture plane

Stage 4 – Enlightenment

Previous research involved a space enlightenment exercise [1] that introduced participants to the concepts of using the sighting technique to determine an imaginary picture plane. Examples of participants work from this previous study are shown in figure 9.

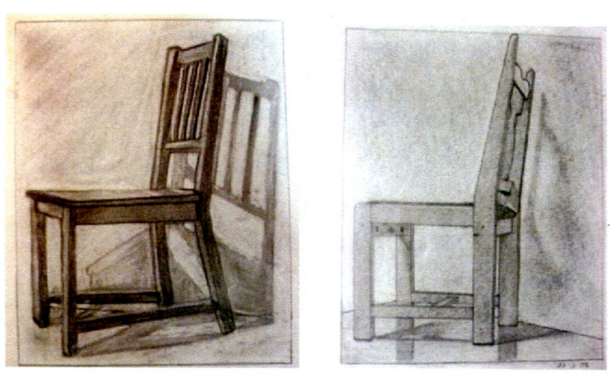

Figure 9 - Space Enlightenment exercise (Lane & Seery 2009)

The space enlightenment exercise has been analysed in terms of applicability for the current research and the following conclusions have been made based on previous findings [1]:

- **Area for development:** The sighting equipment used in the previous research involved a measuring gauge that participants claimed was a source of anxiety due to its difficulty to manipulate, comprehend and apply.
- ✓ **Improvement**: The revised sighting technique using an outstretched arm and pencil will be used. This was applied in the Merging activity (Stage 3).

- **Area for development:** Drawing an artefact such as a chair will not fully enable participants to engage in *metagcognition* and *higher order thinking*. The geometries are excessively regular and the participants already have developed their ability to sight.
- ✓ **Improvement:** Participants will be presented with a selection of furniture that are of regular geometry along with a selection of soft toys which are irregular and varying in texture. Participants will be required to set up a composition in groups of six people (figure 10). The composition needs to be creative and stimulating to draw.

- **Area for development:** The space enlightenment exercise that was used in previous research [1] involved drawing a physical composition that was perceived and a feature that was sketched from memory. It was found that sketching the feature from memory was very beneficial and engaged participants on a higher level of thinking in contrast to the physical object which remained.
- ✓ **Improvement:** A photographic composition exercise will be applied that will challenge the participants on a higher cognitive level by requiring them to draw the composition from memory.

Figure 10 - Setup of classroom for photographic composition exercise along with some configurations which participants created

The photographic composition exercise (figure 10) aims to satisfy the following learning outcomes where participants will be able to:

- Create a suitable configuration and decide the most appropriate seating position to view the geometry
- Analyse the requirements for the activity and decide what critical geometry is recorded. Critical information will include geometries, values, shadow/shade, and textures within the composition. The use of thumbnail sketches and annotations will be encouraged

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- Apply previously used skills to sight and relate geometries to each other within a timeframe of 25 minutes.
- Analyse the critical information that was recorded and engage in critical thought to remember the previously perceived composition on completion at home
- Evaluate and critique the completed composition and make any changes if necessary (as in previous activities)

Stage 5 - Synthesis

A *conceptual challenge* activity aims to harness the abilities developed in previous activities to culminate in a composition that is creative and a large part of which is drawn from imagination. Previous research found that participants (figure 11) had positive feelings, a sense of confidence and satisfaction through engaging in this particular activity [1].

The sole alteration that will be made to this activity from the previous study is the requirement of an increased level of conceptual thought and creativity as it is felt participants are competent to attain a high level. This composition will be used as a covariant in measuring the level of progression from the pre-instruction composition.

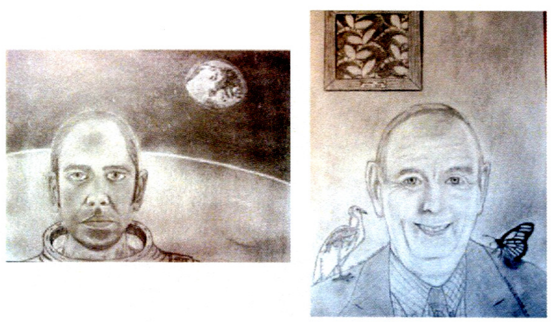

Figure 11 - Selection of Conceptual Challenge compositions [1]

The conceptual challenge activity has the following learning outcomes where participants will be able to:

- Develop a conceptual theme for the composition and determine the position of the critical geometries.
- Synthesise previously developed skills to communicate a creative composition.
- Evaluate the completed composition and critique their personal development.

Findings

In this section the results of all stages of the methodology are detailed. Results include both qualitative and quantitative data in addition to compositions completed by participants. Questionnaires were given to all throughout the four weeks and these

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measured participant level of performance in activities, the value they placed in the activities and areas that they feel need improvement.

Pre-Instruction Activity

Participant results in this activity are very similar to previous research carried out at University of Limerick with the following observations:

- 75% of participants expressed difficulty accurately communicating facial geometries
- 63% found it difficult to resist the temptation to draw child like faces which are very much symbolic in nature
- 85% experienced periods of anxiety and frustration.

Examples of some participant pre-instruction compositions are shown (figure 12):

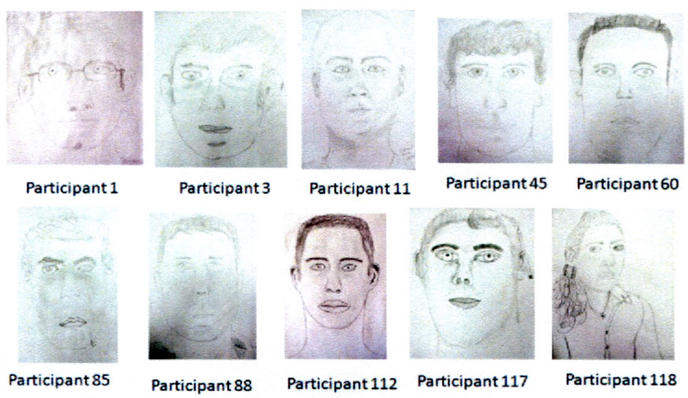

Figure 12 - Selection of Pre-Instruction Compositions

Stage 1 – Recognition

A selection of compositions from the Perception Proof Activity is shown in figure 13 below:

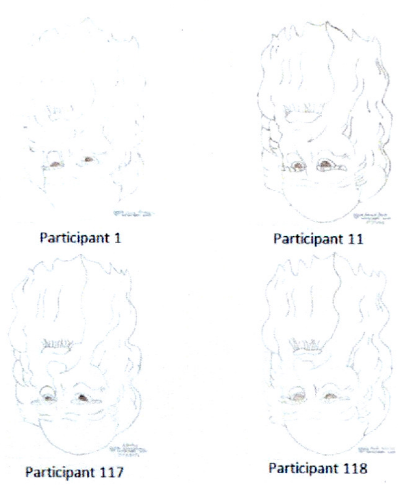

Figure 13 - Selection of Perception Proof Compositions

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Figure 14 illustrates the participants self ratings for their performance in the Perception Proof activity along with the value they placed in the activity.

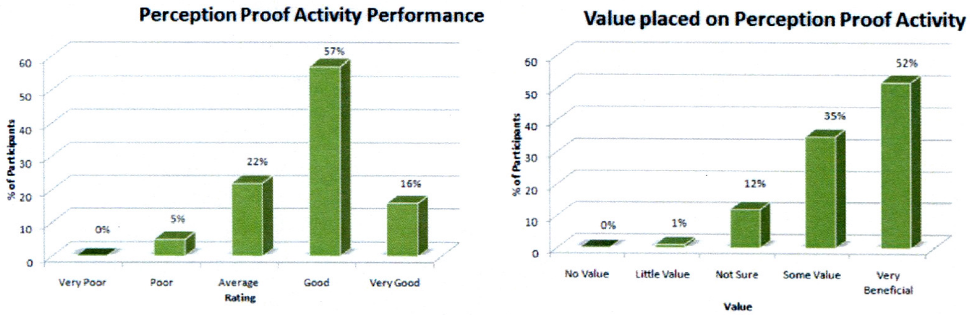

Figure 14 - Participants Ratings on Performance and Value

Stage 2 – Enquiry

A selection of compositions from the Perception Enhancement Activity is illustrated in figure 15.

Figure 15 - Selection of compositions from Perception Enhancement Activity

Figure 16 illustrates the participants self ratings for their performance in the Perception Enhancement activity along with the value that placed in the activity.

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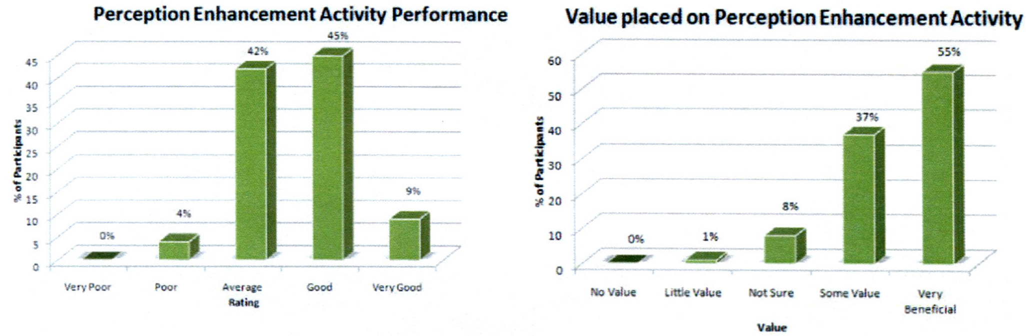

Figure 16 - Participant ratings on performance and value

Stage 3 – Transfer

A selection of compositions from the Merging Activity is illustrated in figure 17.

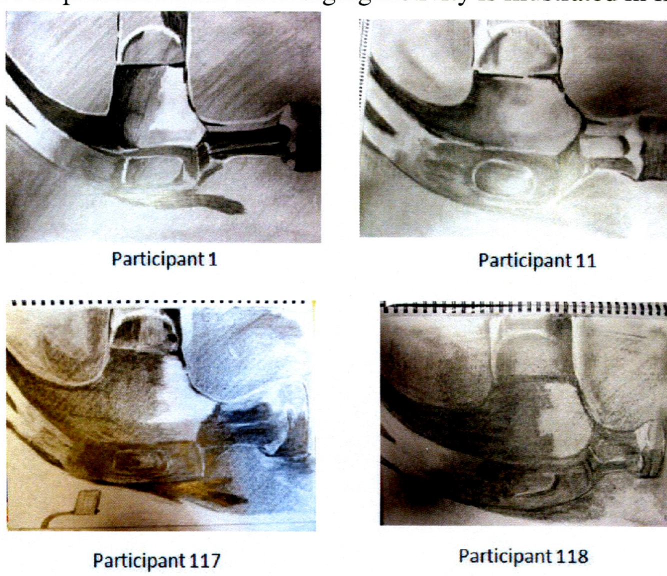

Figure 17 - Selection of compositions from Merging Activity

Figure 18 illustrates the participants self ratings for their performance in the Merging activity along with the value they placed in the activity.

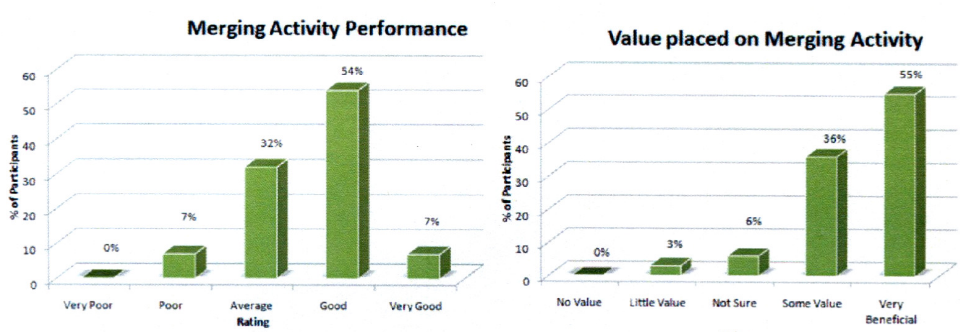

Figure 18 - Participant ratings on performance and value

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Stage 4 – Enlightenment

A selection of compositions from the Photographic Composition Activity is illustrated in figure 19. The smaller compositions are photographs of the physical composition that participants took using the researchers' camera and photographs of the participants work at the end of the twenty five minute timeframe prior to completion at home through memory.

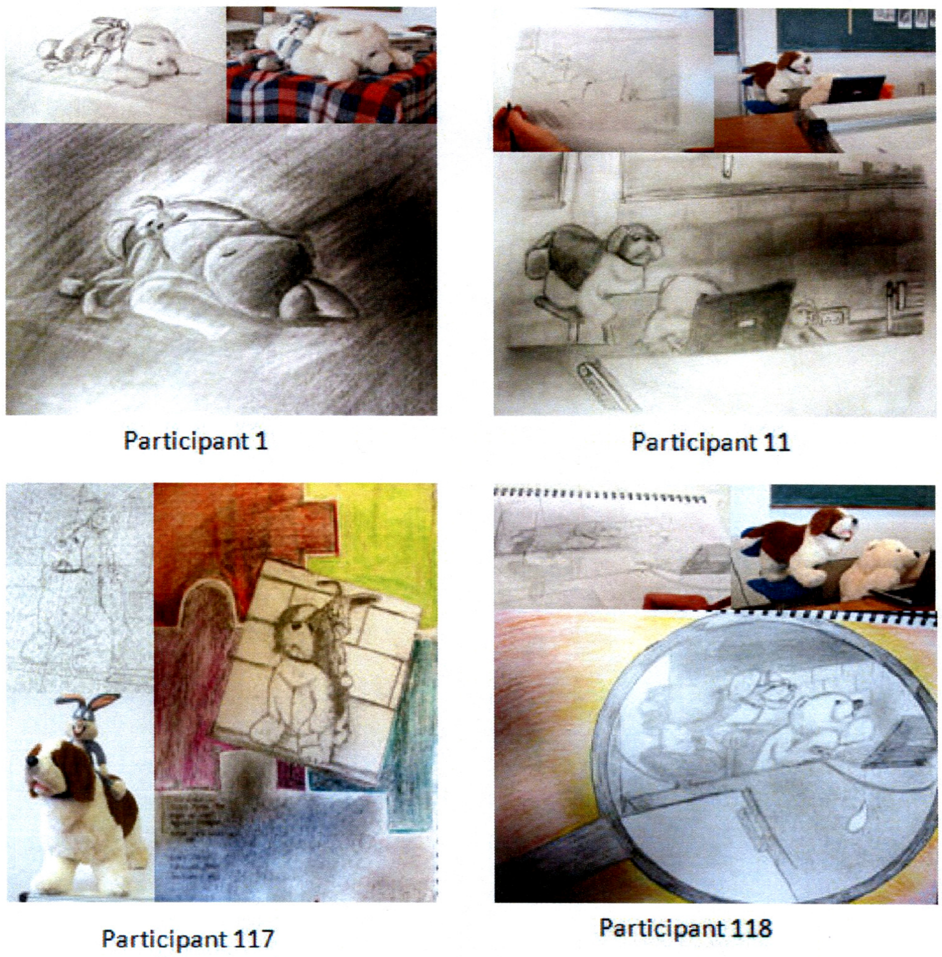

Figure 19 - Selection of participant compositions along with incomplete work prior to completion from memory

Figure 20 illustrates the participants self ratings for their performance in the Photographic Composition activity along with the value they placed in the activity.

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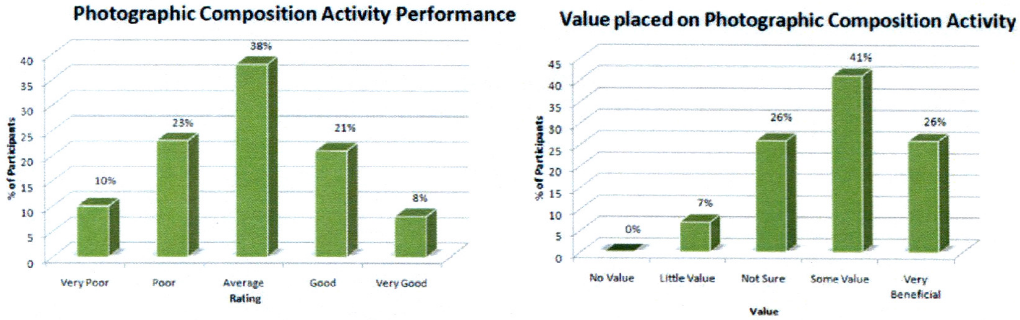

Figure 20 - Participant ratings on performance and value

Stage 5 – Synthesis

All compositions from the Conceptual Challenge Activity along with the pre-instruction composition are illustrated in figure 21 and figure 22.

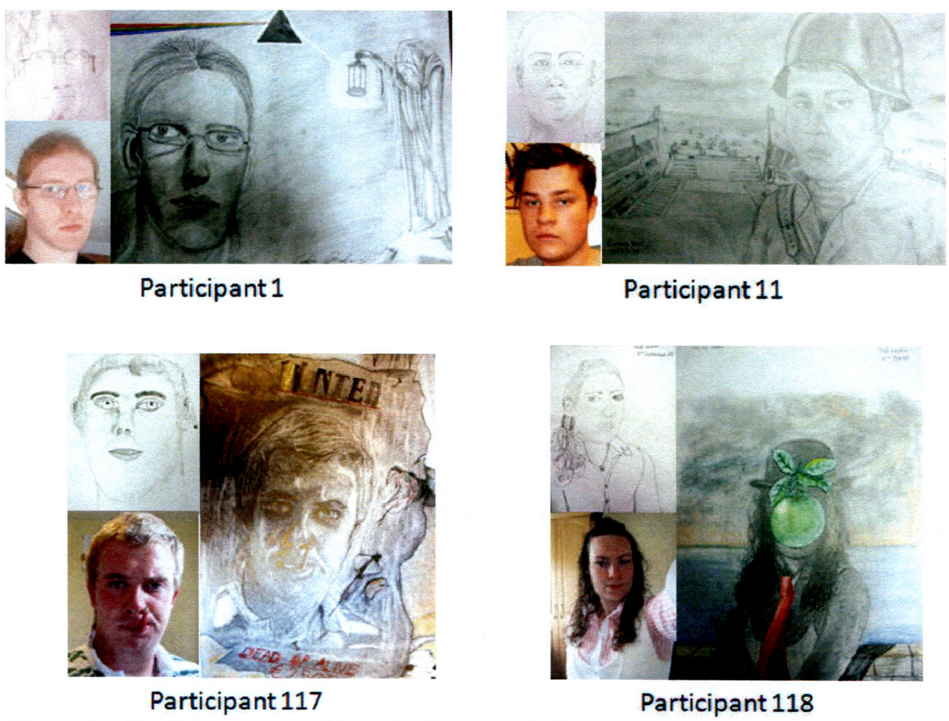

Figure 21 - Participant compositions for Conceptual Challenge activity in addition to the pre-instruction composition and profile photograph

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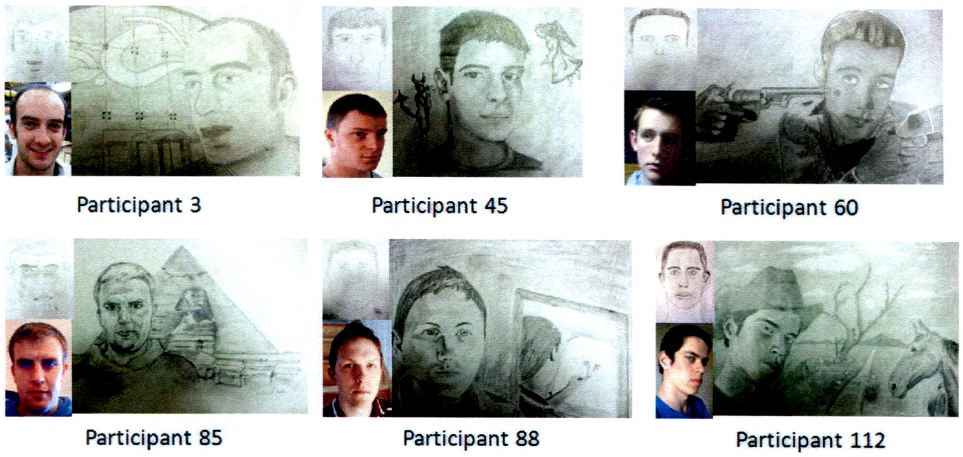

Figure 22 - Remaining participant compositions for Conceptual Challenge activity in addition to the pre-instruction composition and profile photograph

Figure 23 illustrates the participants self ratings for their performance in the Conceptual Challenge activity along with the value they placed in the activity.

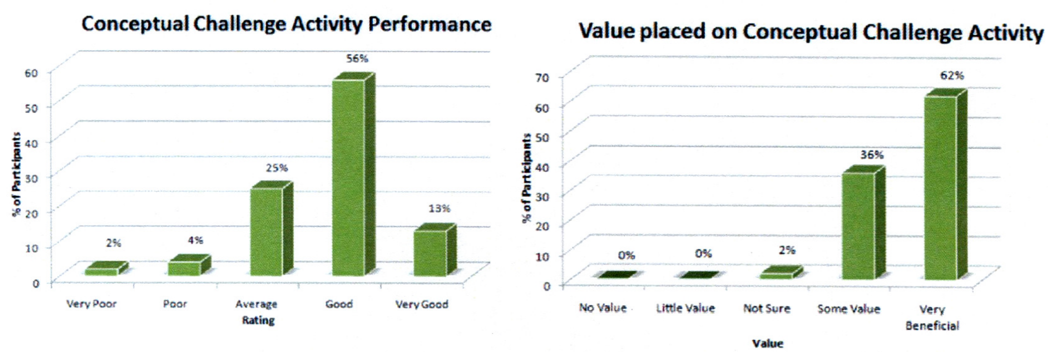

Figure 23 - Participant ratings on performance and value

Figure 24 illustrates the overall effect of the study in terms of participant progression.

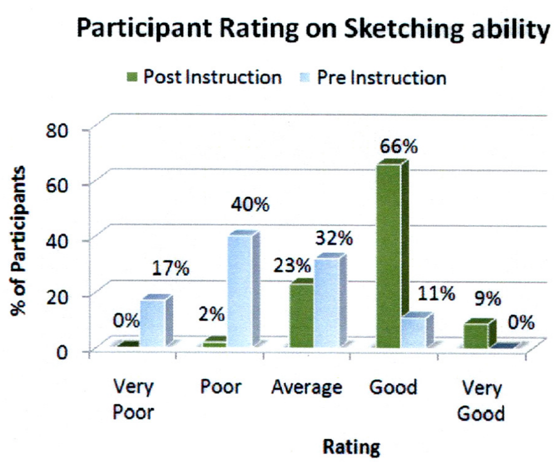

Figure 24 - Participant ratings of pre and post instruction sketching ability

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The holistic value of the activities in terms of developing the ability to communicate through freehand sketching is illustrated in figure 25.

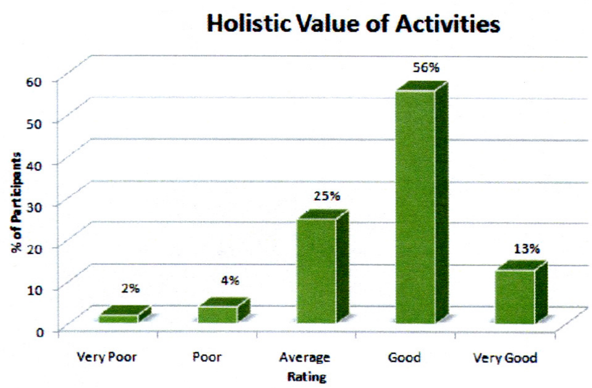

Figure 25 – Participant ratings of holistic value of activities

Both graphs in figures 24 and 25 illustrate data that the participants submitted at the end of the research study. In addition to this participants were asked to select areas of freehand sketching that they would like to develop further in their future study. The results are shown in figure 26.

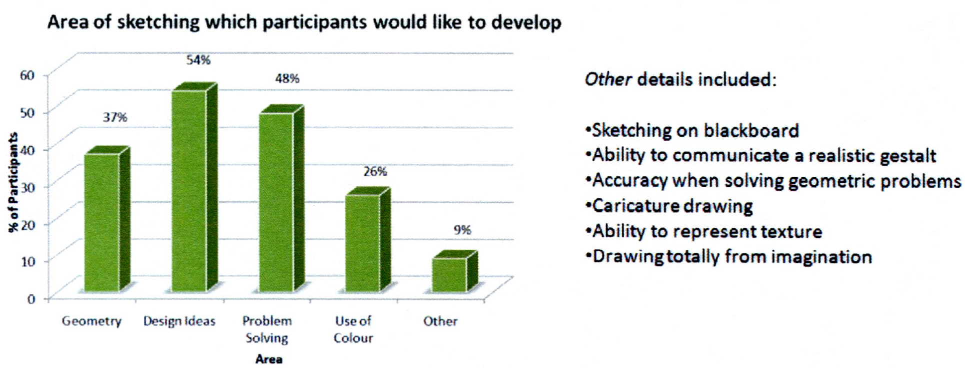

Figure 26 - Areas which participants wish to further improve

The module in which this research study was carried out is twelve weeks in duration. Key areas that are studied by participants are integral to plane and descriptive geometry and are as follows:

1. Principle and auxiliary planes of reference
2. Projection of cubes and tetrahedrons
3. Ellipse, parabola and hyperbola as sections of a right cone
4. Derivation of focal point, focal sphere, directrix and eccentricity in conic sections
5. Intersection of right and oblique solids and their surface development

Participants were required to apply their developed sketching skills to communicate concepts and principles for the problems encountered. A selection of these is illustrated in figure 27.

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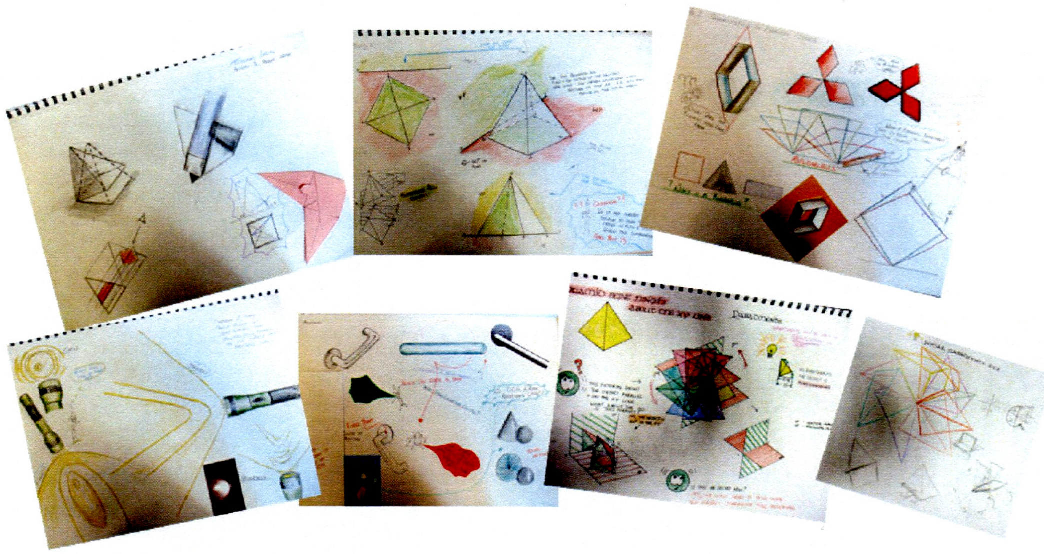

Figure 27 - Selection of participant work based on plane and descriptive geometry

Discussion / Conclusion

This section discusses the results where, the main aims were to determine if the strategy applied by Lane & Seery [1] could be further applied in a large classroom setting with thirty participants in a restricted timeframe of eight hours. The transferability of the developed abilities to problem solving in plane and descriptive geometry and design communication integrated with a pedagogy that coalesced with the principle of *Pareto's Law* will also be explored.

Effectiveness of Strategy

Analysis of participant ratings for the holistic value (figure 25) of the activities throughout the course of the study shows that 94% had a positive experience with 69% rating the value as either good or very good and 25% as average. It can be hypothesised from this finding and observations made that the majority of participants:

- Engaged and were motivated to take part in the activity
- Valued the activities in terms of their personal and holistic development
- Appreciated the planning and preparation involved in addition to the level of teacher interaction
- Found the learning environment and equipment that was applied of benefit and value

The ***Perception Proof*** activity (stage 1) was extremely successful with 87% of participants rating the activity as beneficial or very beneficial) and 95% rating their performance as positive (figure 14). The effectiveness of the strategy in terms of engaging 124 participants in a lecture theatre over a twenty timeframe with outstanding results is very promising. It was an apt activity for inducting participants to the study and this was evident in comments made where participants stated *"I now*

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believe that I can learn to draw" and *"I never thought I could sketch like this... has given me so much confidence and can we do more of these activities?".*

Analysis of participant ratings for the ***Perception Enhancement*** (stage 2) activity indicate that it was very beneficial with 92% of participants stating that it was either beneficial or very beneficial and 96% positively rating their performance (figure 15). Applicability of this in a classroom consisting of thirty students is very suitable with evidence of increased levels of enquiry, recognition of patterns and synthesis between geometries in the composition. Significant holistic value was evident by giving participants autonomy to set up their composition in an imaginative and creative way, while realising the position and importance of the picture plane.

Positive feedback for the ***Merging*** activity is evident. 91% of participants rated the value as beneficial or very beneficial and 93% rating their performance as average, good or very good and this is forward-looking (figure 18). Considering that the activity is a development from previous research [1], it can be assumed that its applicability in a large class situation and its learning outcomes are achievable and of notable benefit in terms of development of perceptual and communication abilities.

The ***Photographic Composition*** activity was a novel activity introduced for this study which had clear learning outcomes in terms of challenging participants and pushing the boundaries for their cognitive development in a restricted timeframe. However, participant ratings of 67% in terms of value and 67% positive ratings (figure 20) for performance indicate that the activity is not as beneficial as the previous three stages. Observations and participant concerns highlight a lack of total understanding on what was required and an overwhelming factor in terms of progressing from sighting a 2D composition to a 3D composition. Based on this, it can be hypothesised that a prerequisite activity needs to be developed that will enable *"distal access"* of the *"physical symbol system"* [26] through communicating more regular geometries from memory which will then lead on to the photographic composition activity.

Analysis of participant ratings for the ***Conceptual Challenge*** activity has positive implications. 98% of participants rated the activity as beneficial or very beneficial while 94% rated their performance positively (figure 23). The level to which participants engaged in the activity is very promising and it is obvious that the assimilation of developed skills into a conceptual activity was a source of motivation and reward for participants.

Implications for Teaching and Learning

Sketching is an integral tool in the design process, for communicating concepts and ideas in addition to recording and sharing relevant design information [29]. It can be hypothesised that the applied strategy, developed a critical set of abilities in participants that caused them to engage in *metagcognition"* [18] and higher order cognitive development [7]. An understanding of the cognitive architecture [22] contributed to a deeper insight into how participants think and was instrumental in devising a pedagogic structure based on the *"80/20 principle"* and *"Pareto's Law"* [14]. The application of an eight hour strategy coupled with incubation periods of one week proved successful when integrated into a forty hour module that allowed participants to transfer their skills into solving problems in plane and descriptive geometry (figure 27).

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Based on participants ratings of their pre and post instruction compositions (figure 24), it can be categorically concluded that a significant level of improvement was attained by 96% of participants. This is reinforced by visual comparison of pre and post instruction compositions together with profile photographs (figures 21 & 22). Further development of sketching skills to improve the ability to communicate design ideas (54%) and problem solving in plane and descriptive geometry (48%) (Figure 26), indicate that there is significant need for the development of approaches that synthesise and advance sketching abilities.

Summarising the implications of the strategy in terms of integrating freehand sketching skills with problems in plane and descriptive geometry and design communication, the participants are now able to:

- Engage in *metagcognition* and *symphonic thinking* to apply core skills in solving problems in areas of communication graphics while adding to a repertoire of *concept driven competencies*.
- Retrieve information through *"distal access"* of the *"physical symbol memory"* to communicate geometry from short and long term memory in conceptual activities.

Future Research

1. The development of an assessment technique that will measure the level of improvement in participants from the pre-instruction to post-instruction stages.
2. Further analysis of the transferability of developed abilities in design communication and problems in plane and descriptive geometry with particular reference to the *physical symbol system* [26].
3. As spatial visualisation skills are important for success in engineering [30], evaluation of participant's spatial abilities pre and post instruction needs to take place to establish if improvement is occurring contemporaneously.

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Hard Copy to Digital Transfer: 3D Models that Match 2D Maps

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Abstract

This research describes technical drawing techniques applied in a project involving digitizing of existing hard copy subsurface mapping for the preparation of three dimensional graphic and mathematical models. The intent of this research was to identify work flows that would support the project, ensure the accuracy of the digital data obtained, and provide a means of capturing, realizing, and extending the value of an existing investment in subsurface mapping. Mapping used in this project was in hard copy format. Control points for use in digitizing were converted from local coordinates to plane coordinates based on a defined map projection. Since mapping done in this work was to meet National Map Accuracy Standards, calculation of acceptable root mean square digitizing error was necessary and is demonstrated. Two methods are discussed to ensure quality control in digitizing. Preparation of base maps showing drilling data provides a means of estimating map *accuracy*. Map *precision*, however, is shown by comparing the congruence of contours as digitized and contours as obtained from the digital model. Where congruence is lacking, the digitizing of supplemental contours or direct editing of the grid itself is required to precisely constrain the 3D model. Efficient work in this project was heavily dependent on use of standard techniques of engineering graphics. To expedite digitizing, a common layering scheme was developed for all oil fields mapped. Control points used in digitizing were selected so as to be common to all mapping, even where multiple maps were involved. In addition, the use of a common map format, color scheme, lettering style, and included metadata materially expedited the work. Finally, the conduct of the work in defined stages provided immediate work products from the project. This facilitated identification of needed changes early in the project and supplied accurate data as soon as digitizing on a specific field was complete.

Introduction

Manual digitizing is a common task for any engineering graphics application where three dimensional (3D) models must be generated from existing hard-copy mapping. The use of digitizing is particularly appropriate where significant interpretative effort was necessary to develop the initial map. This would be so, for example, in the interpretation of subsurface structures from drilling logs used in energy exploration. Conceptually, there would seem to be little difficulty in digitizing; the drafter generates a set of x, y, z coordinates from either a scanned image or from a paper map affixed to a digitizing table. The set of coordinates so generated is then used for 3D modeling of the surface of interest.

Despite this conceptual simplicity, anyone who has digitized will readily attest to the difficulty of obtaining a mathematical model that closely matches the original image or map. Triaxial coordinates resulting from digitizing may produce questionable surfaces, innovative shapes, and spurious artifacts. Such results are especially frustrating when

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project planning assumes high production from digitizing and anticipates seamless data transfer into modeling. Further, because digitizing is the initial phase in much work, the project schedule can be immediately impacted when digitizing fails to proceed as planned.

A series of recent projects involving hard-copy-to-digital conversion of existing maps of oil and gas fields in the Illinois Basin provided an opportunity to study work flows, quality control methods, and engineering graphics techniques for manual tablet digitizing. The digitizing involved was designed to support the development of 3D models. Technically, digitizing and modeling in the subsurface must reflect the control on the model of faults within the structures mapped. This is because faults impact both digitizing itself and the model generated from the digital data set. Specifically, the following questions were addressed in this research:

(1) How can a common plane coordinate system be employed to facilitate large scale engineering mapping and yet provide for the use of specific map projections for small scale mapping?
(2) What techniques during digitizing are necessary to ensure an accurate data set? and
(3) How can faulting be accommodated during mapping and modeling?

Background

As noted by Bitters (2009), the use of existing information sources—including the digitizing of hard-copy mapping—is a common method of geospatial database development. Despite the availability of spatial data in the public domain, Lo and Yeung (2007) note that for much work in-house digitizing of existing maps continues to be an important part of system development, particularly where mapping is company-owned and proprietary.

Manual digitizing can be done using a digitizing table, or the image to be digitized can be scanned and then displayed and digitized on a computer screen. In either case, the map being digitized must be calibrated to known control points. Lo and Yeung (2007) describe the calibration process as a mathematical transformation that relates map to digitizer coordinates. Demers (2005) notes that digitizing software typically computes and displays calibration precision using the root-mean-square (RMS) error.

The numeric data resulting from digitizing are a marketable commodity. Large scale mapping for engineering purposes is distinctly different from the small or medium scale mapping available in the public domain. Prior to digitizing, industrial map products must be georeferenced to a defined map projection, plane coordinate system, and vertical datum. During digitizing Demers (2005) suggests use of a clear order for features to be digitized to ensure that omissions (and subsequent editing) are minimized. He also suggests using a defined list of attribute names to facilitate later data sorting. The importance of the projection, coordinate system, and vertical datum to later data users is recognized by Krygier and Wood (2005), who state that the drafter should include these in map metadata.

Digitizing hard-copy maps is a labor intensive and expensive process (Longley et al., 1999). Bitters (2009) states that the features and level of detail digitized depend not only on the level of detail resolvable, but on economics as well. Demers (2005) suggests that data digitized be limited to that necessary to the goals of the work being done, while Kellie (2010) notes that hard-copy-to-digital conversion provides additional return on investment by facilitating further use of existing mapping.

The labor intensive nature of digitizing makes it necessary to consider both methods of reducing the amount of digitizing and techniques for ensuring digitizing accuracy. Lo and Yeung (2007) prefer the use of point digitizing rather than data streaming because point digitizing enables the operator to select specific points to digitize, resulting in a smaller point set. Walsh and Brown (1992) discuss techniques for evaluating digitizing accuracy including (a) redigitizing, (b) use of a map overlay, and (c) volume computation using different algorithms. Kellie (2009; 2010) applied the graphic overlay technique—which he termed the congruence method—to subsurface mapping as a means of ensuring digitizing accuracy.

Faulting is a special problem that influences three dimensional modeling in the subsurface. Faulting controls the location of digitized contours and must itself be included in the data set produced. Kellie (2009) described the impact of faulting on digitizing and subsequent 3D modeling done on two Kentucky oil fields where structural contours being digitized terminated at the fault. The fault itself was digitized and used to blank cells in the 3D model prior to data gridding. The result was that structural contours were not extrapolated across the fault, and structure was modeled correctly.

Study Areas

Based on the above work, research was undertaken to address the three questions posed at the beginning of this paper. To do this, existing mapping was digitized for the Poole, Hanson, and Midland fields in the Illinois Basin of Kentucky. The outcome of this work for each study area included both the graphical result of the physical digitizing and a data file with a set of x,y,z coordinates that mathematically defined the surface mapped.

Coordinate Systems

The source maps used in this project were based on the Carter coordinate system used by the Kentucky Geological Survey (KGS) to archive oil and gas data. Vertical positions were defined by use of mean sea level (MSL), which usually referred to the National Geodetic Vertical Datum of 1929. The Carter coordinate system uses a number-letter-number system to specify location to a 1x1 minute grid; positions within each grid then are designated by the distances from the north (or south) and east (or west) grid lines

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(Nuttall, 2009). For example, a drilling location might be specified as 1000 FNL x 2000 FEL 3-G-38. This translates to “1000 feet from the north line by 2000 feet from the east line of 1 minute grid 3 in row G column 38”. The Carter coordinate system mixes geodetic coordinates (latitude and longitude) and plane coordinates (distance in feet). This makes coordinate conversion necessary if a set of points is to be defined by a set of unique x,y,z coordinates.

In this research, all mapping was digitized using the Kentucky State Plane Coordinate System (SPCS), South Zone. To do this, Carter coordinates for a minimum of four control points on the each original map were expressed as x, y coordinates of the Kentucky SPCS using the Coordinate Conversion Tool of the Kentucky Geologic Survey (KGS) (KGS 2010; NGS, 2009).

All digitizing in this project was done using a Calcomp digitizing table and Didger software (Golden Software, 2001). The table was calibrated to each map so that digitized points represent real-world positions. Following calibration point digitizing, the Didger software displays the root mean square (RMS) error of the calibration.

The source maps used in this work were of unknown accuracy. Resulting map products were prepared to National Map Accuracy Standards (NMAS) (Ghilani & Wolf, 2008). These require that for map scales larger than 1:20,000 not more than 10 percent of points tested shall be in error by more than 1/30 inch at map scale. For maps smaller than 1:20,000 the limit of horizontal error is 1/50 inch at map scale. Then, mathematically,

$$E_{90} = E_{68} \cdot C_{90} \quad \text{...(1)}$$

where E_{90} = error at 90% confidence interval; E_{68} = RMS error; and C_{90} = 1.6449 the factor yielding 90% of the area under the normal distribution curve.

For example, the map of Poole Consolidated Field is at a scale of 1:12,000 (1 inch = 1000 feet). Then

$$E_{90} = 1{,}000 \cdot \left[\frac{1}{30}\right] = 33 \text{ feet} \quad \text{...(2)}$$

$$E_{68} = \frac{33}{1.6449} = 20 \text{ feet} \quad \text{..(3)}$$

For Poole, calibration was considered successful if RMS calibration error was less than 20 feet. There was little difficulty in obtaining the required calibration error; when RMS error exceeded that as computed above, the reason was usually a mistake in coordinate entry rather than digitizing problems. From an engineering graphics standpoint, if the

RMS error in calibration is acceptable, data and graphics resulting will have correct position, orientation, and scale.

Quality Control for Digitizing

The first map digitized showed structural contours mapped at the Poole Consolidated Field, Webster County, Kentucky. Original field mapping was by Cowan (1988) at a scale of 1:12,000. For model calibration, Carter coordinates for four points on the map were converted to Kentucky SPCS positions as described above.

Standard graphic layers were created for (a) structural contours, (b) gas wells, (c) oil wells, (d) dry holes, (e) a mask, (f) a background, and (g) text. A supplemental contour layer was added following data export and a check of contour congruence. Experience in this project strongly reinforced the importance of using standard layers during data capture. This not only organizes digitized data, but minimizes editing of multiple data sets. Graphic results from digitizing are shown in figure 1.

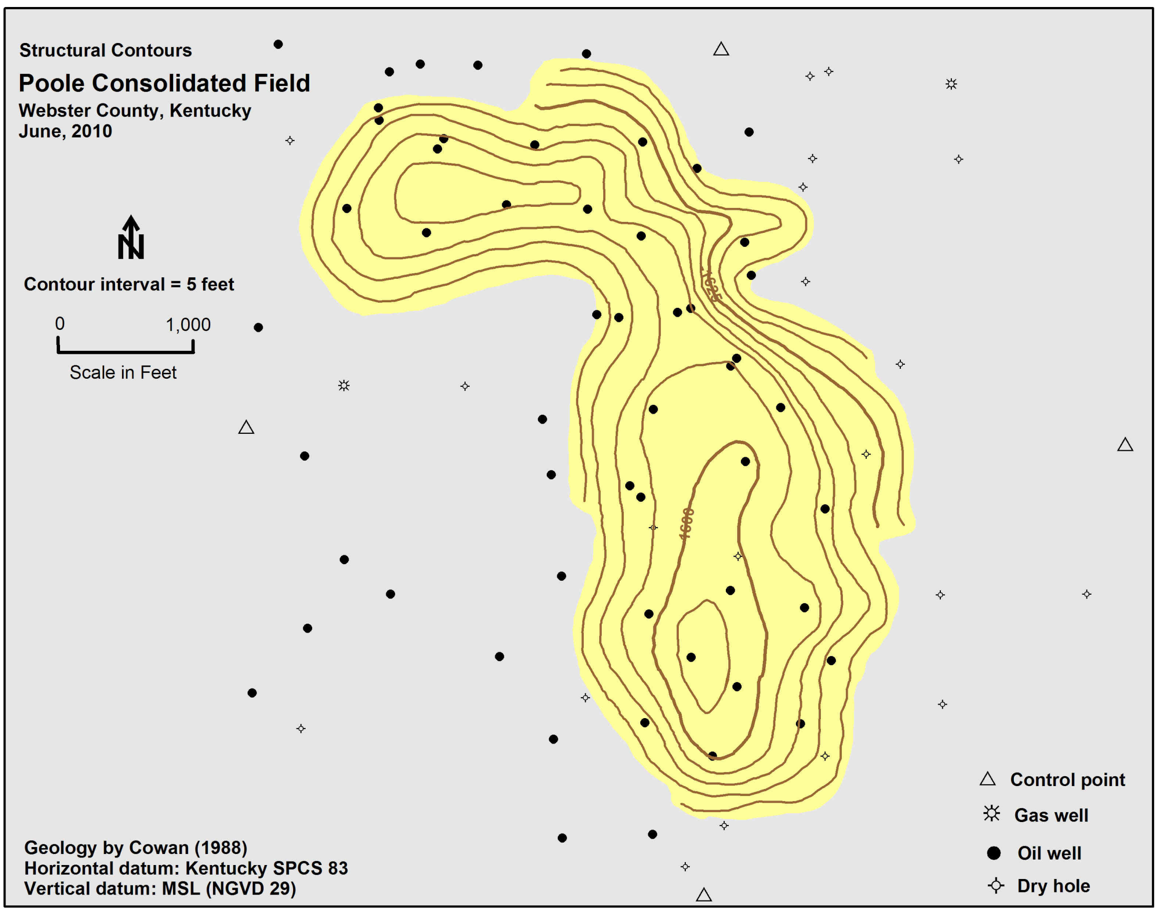

Figure 1. Results of digitizing at Poole Consolidated Field. Drilling data shown indicates extent and distribution of data used for contouring.

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After digitizing, structural contour data was exported to Surfer (Golden Software, 2002) mapping software as both coordinate (x,y,z) and graphics files. The coordinate data were gridded using the minimum curvature algorithm. The mask layer was used to blank gridded data outside the area mapped, and a structural contour map based on the gridded data was prepared.

Initial digitized data frequently result in artifacts that present as mislocated contours. This can be rectified by constraining gridding with additional data. To do this, a supplemental contour layer was created, and supplemental contours were digitizing. Original and supplemental elevations were then output as a data file, regridded, and plotted as a new contour map. The original graphic file was overlain once again to check congruence. The final result for Poole is shown in figure 2.

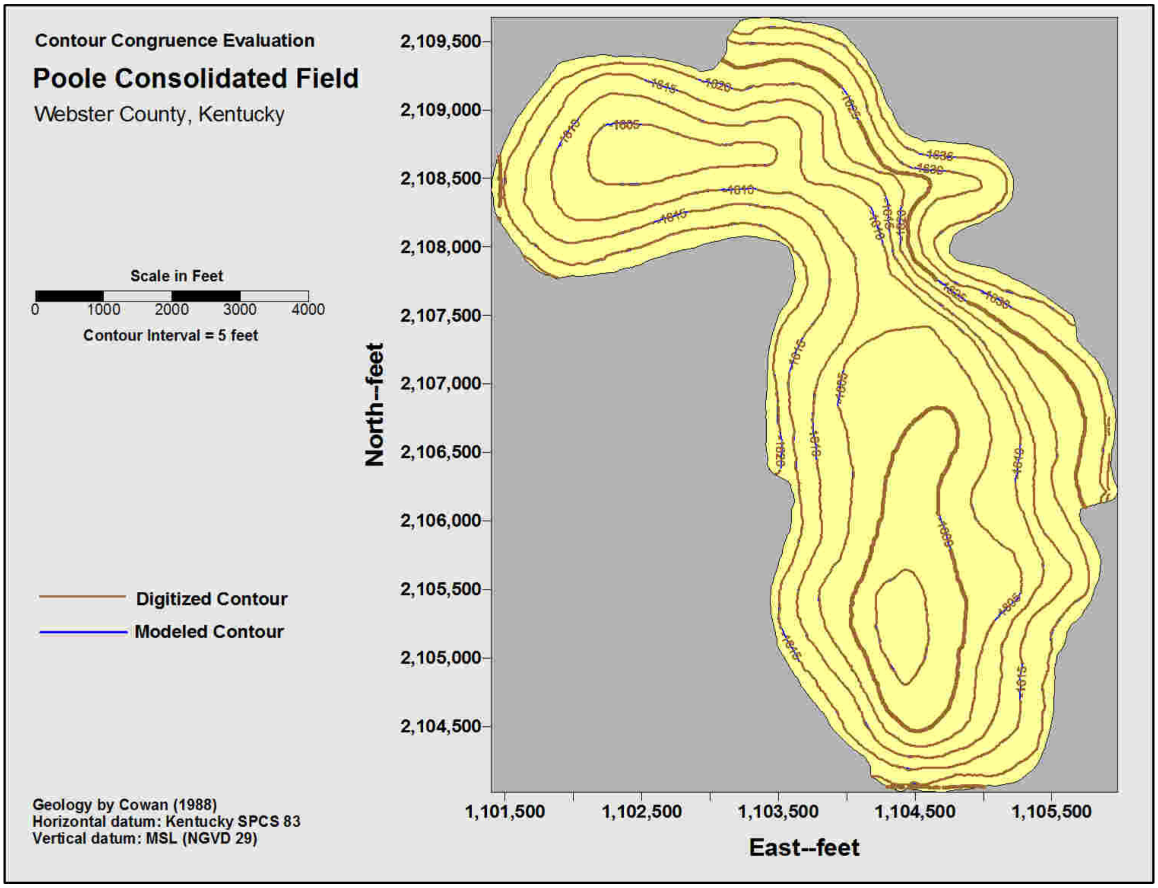

Figure 2. Results of digitizing, gridding, contouring, and editing for Poole Consolidated Field. Digitized and modeled contours are congruent, indicating a correct mathematical model.

The work above uses two quality control checks. First, *precision* of contouring was measured by the congruence of modeled and graphic contours. Second, map *accuracy* was evaluated by posting well locations on contour map. Because drilling was the basis

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for contouring, the density and distribution of drilling controls the amount of interpretation used in contouring.

The maps in figures 1 and 2 originally were intended as in-house map products, designed to be printed in C size format. Both are check maps. Figure 1 shows the location and extent of features digitized. By showing drilling, it helps the map user evaluate map accuracy. Figure 2 checks the precision of contouring by showing congruence of the digitized and modeled contours.

When the maps used for figures 1 and 2 were modified for use in this paper the standard title block was removed and replaced with the map title and purpose shown in at the upper left of each figure. A light gray background for the entire drawing and a pastel background for the map proper were selected to minimize eye fatigue. Lab standard color coding is used for digitized and modeled contours; industrial standard symbols are used for gas wells, oil wells, and dry holes. All lettering in this research uses an Arial (sans serif) font. A sans serif font was selected to avoid lost detail due to map reduction and screen resolution issues. Map metadata are included on each map.

A coordinate grid is not shown on figure 1 to limit clutter. Structural contours in figure 1 follow the convention of using a heavy line and label for index contours. A lighter, unlabeled line was used for intermediate contours. In Figure 2, every contour line is labeled with an elevation to facilitate editing. Drilling locations are not shown, having already been presented in figure 1.

The second set of maps digitized showed structural contours and isopachs (thickness contours) of the Tar Springs Sandstone at Hanson Field, Hopkins County, Kentucky. Here two different maps had to be overlain. The field itself and the area of the Tar Springs Sandstone (the principal petroleum reservoir) are shown in figure 3.

For model calibration, Carter coordinates for five points control points were converted to Kentucky State Plane Coordinates (1983) as described above. Control points were selected so that they could be used for both maps. Structural contour digitizing was generally unremarkable. Isopachs, however, had relatively wide spacing and required supplemental digitizing to constrain the mathematical model. Isopachs for Hanson Field are shown in figure 4.

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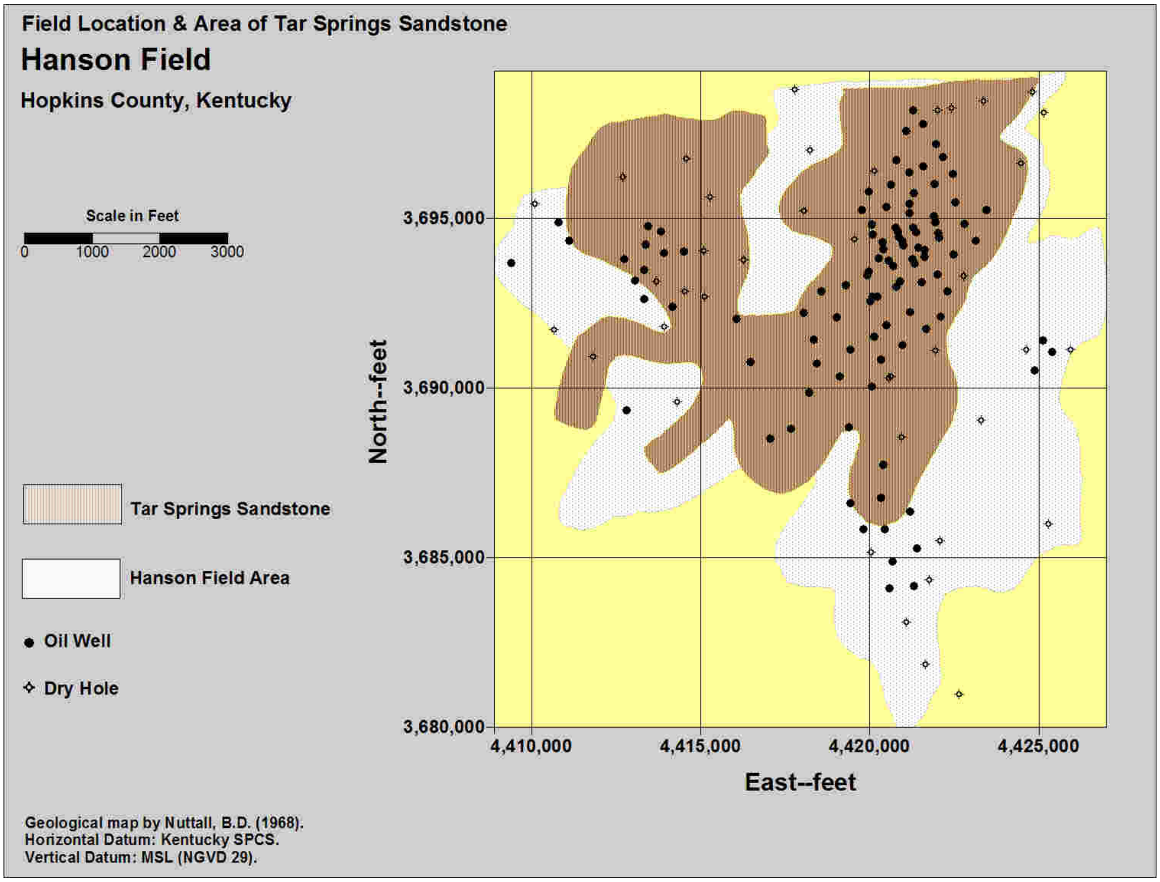

Figure 3. Hanson Field, showing total area and area of Tar Springs Sandstone reservoir.

Figure 3, which was prepared in Surfer (Golden Software, 2001), overlays the structural contour, isopach, oil well, and dry hole layers generated from digitizing. Field extent is shown with a light pattern on a pastel background. The area of the Tar Springs Sandstone Reservoir is shown using a significantly darker pattern. Colors represent those of the natural rock.

Figure 4, also prepared in Surfer (Golden Software, 2001), overlays graphic isopachs from digitizing with isopachs generated from the gridded data. Significant digitizing of supplemental contours was needed to obtain the congruence shown.

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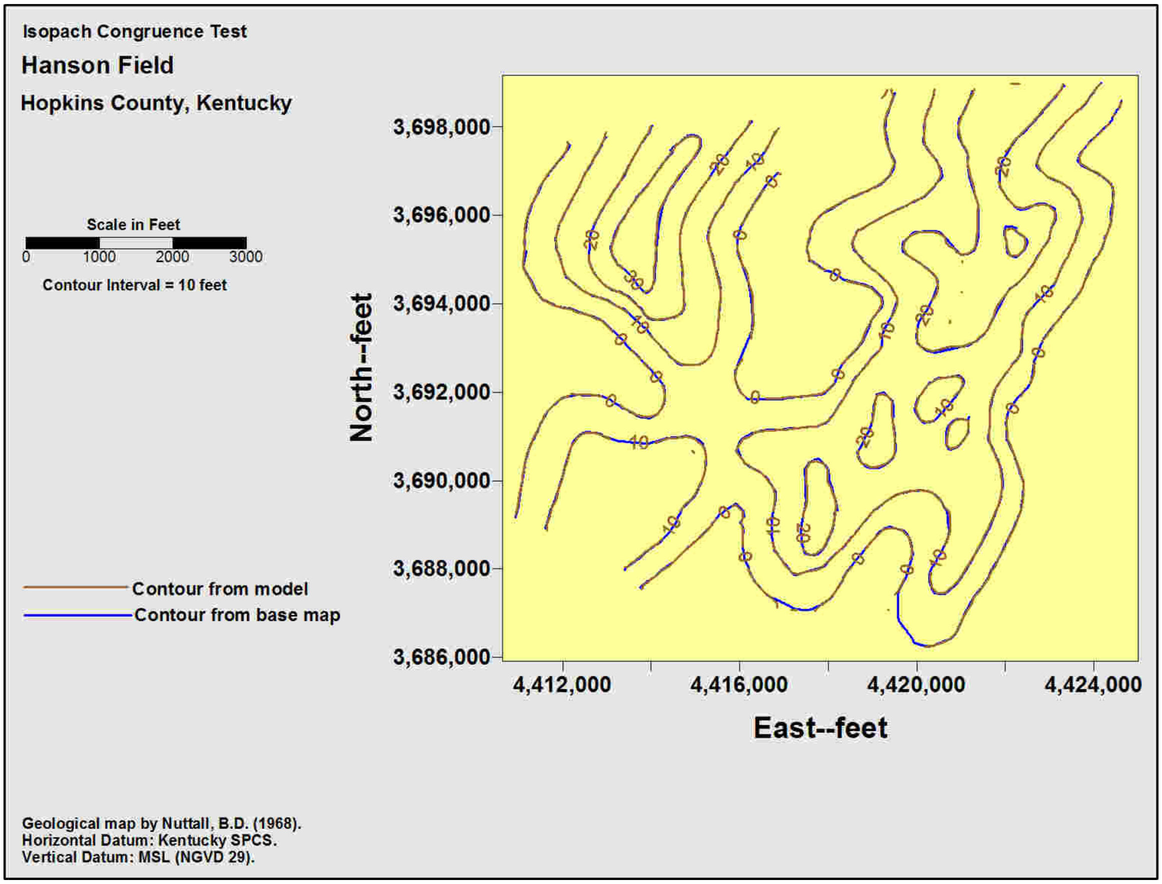

Figure 4. Isopachs of the Tar Springs Sandstone, Hanson Field, Hopkins County, Kentucky.

The final study area used in this research was the Midland Field, Hopkins County, Kentucky. This field was selected because it has faults that control structural contouring. Structural contours obtained from digitizing are shown in figure 5.

As figure 5 shows, mapping at Midland Field was based on drilling that had very irregular distribution. Contours are not continuous across the fault located in the center of the field, and contours terminate at the fault located in the southeast quadrant. During digitizing, a mask file was prepared to blank gridded data outside field boundaries. Fault lines were digitized and used to blank the grid cells along each fault. The blanked cells cause contours to terminate along the fault.

The congruence evaluation for Midland is shown in figure 6. This shows minor artifacts to be edited, but most of the contouring (including that along the faults) is congruent.

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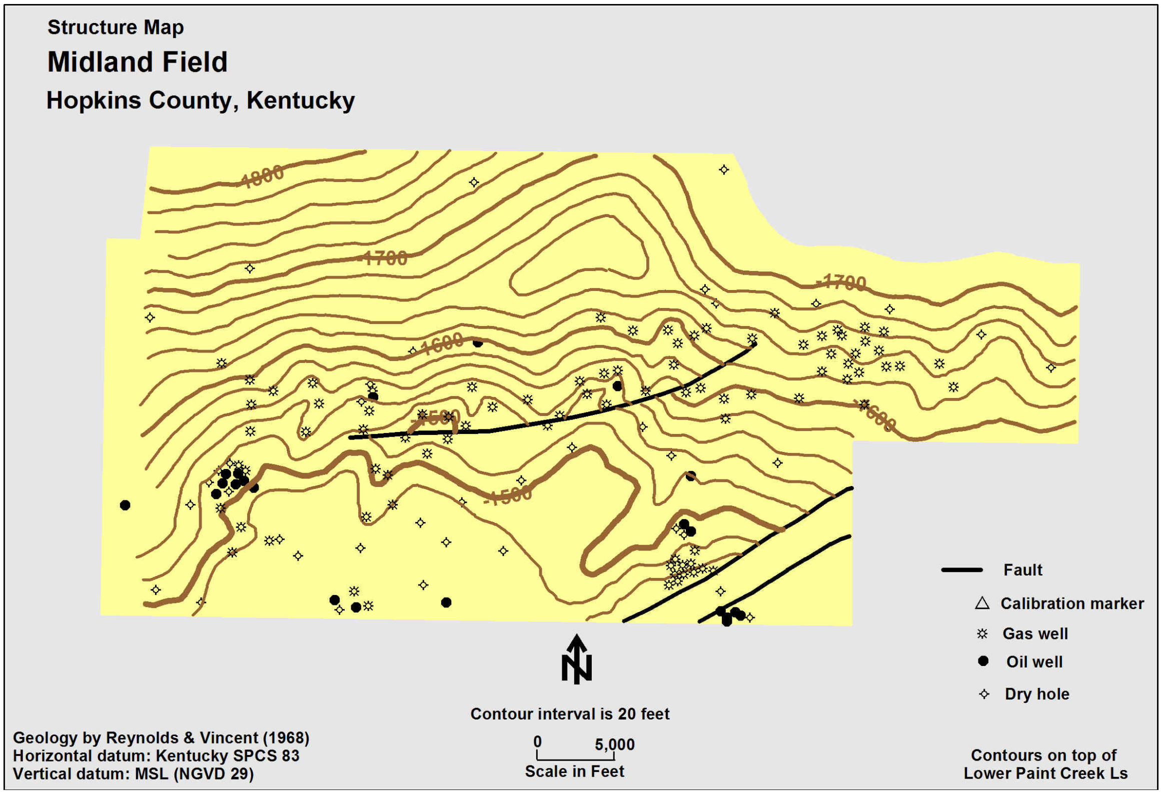

Figure 5. Structural contours at Midland Field, Hopkins County, Kentucky.

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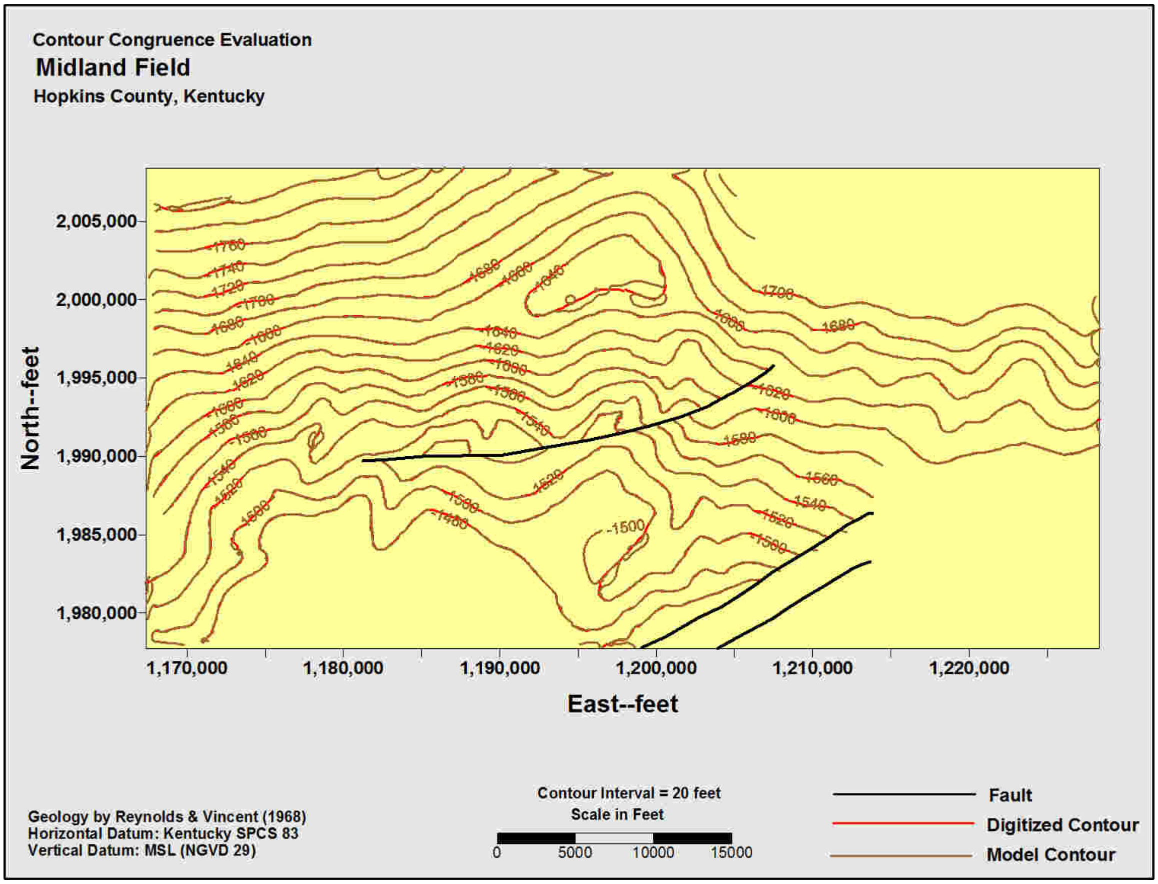

Figure 6. Congruence evaluation, Midland Field, Hopkins County, Kentucky.

Conclusions

The work done in this research demonstrated four things. First, despite the unique nature of subsurface mapping, the basic techniques of technical drawing were fundamental to the successful conduct of the work. These fundamentals included use of a standard layering scheme, standard map arrangement, uniform lettering styles and sizes, use of a bar scale and statement of contour interval, designation of orientation, and provision of map metadata including horizontal datum, vertical datum, and data source.

Second, use of a defined coordinate system provides map products with known distortion and a specified relationship to other coordinate systems. Calculation of acceptable calibration error for the project being digitized provides an immediate check on coordinate conversion, point identification, and digitizing precision. The work done in this project confirmed lab experience with digitizing error obtained in previous work: if the calibration error is larger than expected, something is wrong and correction is required before work proceeds.

Third, quality control for digitized map products involves both accuracy and precision. A map is no more accurate than the data on which the map is based. For this reason, preparation of base map overlays showing drilling location and distribution is fundamental to understanding map accuracy. Comparison of the congruence of contouring obtained from digitizing with contours drawn from the gridded model tests mapping precision. Testing by congruence involves overlaying the digitized contour base map with contours generated from the gridded data file. Experience in this project showed that closely spaced, regular contours yielded models requiring little editing. Where contouring was widely spaced and irregular, supplemental contours had to be digitized in order to constrain the mathematical model.

Fourth, the constraints on contouring imposed by faulting and the potential for gridding routines to extrapolate beyond data limits must be recognized when 3D data is digitized. While this research employed a blanking method to control data expression in these cases, the specific technique employed is not as important as ensuring that the data produced for modeling accurately represents the surface being modeled.

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