UNIVERSITY
Of
GLASGOW

Secondary School Technological Problem Solving: An Investigation of Factors Associated with Levels of Success

by

Mr. David Morrison-Love
BTechEd (hons.)

A thesis submitted in fulfilment of the requirements for
the Degree of Doctor of Philosophy (Ph.D.)

Robert Clark Centre for Technology Education
School of Education, College of Social Sciences,
University of Glasgow

May 2013

Abstract

Research into school-based and real-life technological problem solving has shown it to exist in a range of forms and draw upon a number of constituent processes and knowledge types. While this has given much needed insight into what happens when pupils undertake such problem solving in classrooms, there is little understanding about the relationship between these constituent elements and pupil performance on problem solving tasks. Moreover, such tasks are often still undertaken individually within schools. This thesis builds directly on this by offering a definition for classroom-based technological problem prior to developing a mixed-method approach that allowed the problem solving activity of four high performing groups to be compared with that of four low performing groups. Single gender groups of approximately four pupils worked through a well-defined cantilever problem task in three Scottish technology education classrooms. The group performance was determined by outcome.

Findings from the comparative analysis revealed differences in three key areas. Firstly, higher-performing groups naturally employed better process-management strategies including use of planning, role and task allocation with lower levels of tension between group members. Secondly, higher-performing groups made more use of reflection in which reasoning was verbalised, with the potential to promote better shared understanding between group members during the solving process. Thirdly, higher-performing groups exhibited a greater level of tacit-procedural knowledge within their final solutions. Additionally, there was evidence that lower-performing groups were less affected by the competitive task dynamic, and were not always as comprehensive in transferring prior understanding to the problem solving context.

These findings were largely consistent between groups and form a basis upon which approaches to pedagogy and assessment can be considered and developed to raise the capability and performance of those pupils who find such problem solving more challenging. Moreover, the findings pertaining to process management and the nature of reflection have wider implications for learning and teaching in related areas of STEM Education.

Dedication

This thesis represents the start of a new chapter in my life, and offers closure to an existing one. I would like to dedicate this work to four important people in my life.

First and foremost, to my wife Lynne whose enduring love, support, encouragement and patience have given me strength when I would otherwise have had none. I am deeply proud to be her husband and will love her always.

Secondly, to my son Daniel. He is special to me in so many ways and means more to me than I can express. Though only three, he is a bright, happy boy who I hope will grow to be proud of me as I already am of him.

I also dedicate this work to the loving memory of my mother, Heather, who was lost to me many years ago. She was a bright, loving and humorous person who gave me the start in life that made so much of this possible. She was often in my thoughts during the low points and high points of this work.

Finally, it is with loving sadness that I dedicate this to my son Andrew, who was taken from us in the course of these studies and before I was able to know him as a person. He will forever be in my heart and I hope that he too is proud.

Contents

List of Tables

List of Figures

List of Accompanying Material

CD-Rom of Audio Excerpts and Support Material (Enclosed)

Acknowledgements

I would, first and foremost, like to extend my deepest gratitude to my supervisors, Dr. Jane V. Magill and Dr. Alastair D. McPhee, for their unfaltering guidance and sage academic insight throughout what has been a challenging but rewarding period in my life. Their differing academic backgrounds naturally complimented the considerations and investigation in this study and offered a rich and unique source of expertise I am fortunate to have benefited from. I am in little doubt that without their pragmatism and considered thoughts, achieving this would not have been possible. Thank you.

I would also like to thank Dr. Brain Canavan, a friend and fellow post-graduate who offered his time, guidance, reassurance and numerous challenging academic discussions that have undoubtedly sharpened my understanding and broadened my perspectives. This has been invaluable and deeply appreciated.

As a practicing teacher of Technology Education at Braes High School during my studies, I am indebted to my Faculty Head, Mr. Tommy McKinlay, my colleagues in the Technology Department and, notably, to my Head Teacher, Mrs. Helen McCulloch. The level of support, encouragement and understanding offered by these individuals was truly significant in the least and I will be forever grateful for this.

I would like to thank the Underwood Trust who granted me the Scholarship that allowed my post-graduate studies to take place, and Dr. Alexander MacKinnon and the Graduate School for supporting me through these during some very challenging times. This opportunity has significantly reshaped my life, excited and inspired me to pursue my future career in Educational Research.

I would like to extend my thanks to Professor Frank Banks and Dr. Alexander MacKinnon for undertaking the review process and helping to improve and refine this thesis. My thanks also go to Dr. Margaret Pollock who undertook the task of proof reading this document.

Finally, I am acutely aware that such a significant achievement would not have been possible without the encouragement, help and strength from my wife, my son, and my family. My gratitude is immeasurable and to all of you, I thank you now and always.

Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, this thesis is the result of my own and has not been submitted for any other degree at the University of Glasgow or any other institution.

Signed:

David Morrison-Love.

May 2013.

Abbreviations

ACfE	A Curriculum for Excellence
fMRI	Functional Magnetic Resonance Imaging
G	General Intelligence
G*c*	Crystalline Intelligence
G*f*	Fluid Intelligence
HS	Higher Still
LEA	Local Education Authority
S2	Secondary School, Year 2
SADI	Scottish Area Deprivation Index
Sd	Standard Deviation
SG	Standard Grade
SQA	Scottish Qualifications Authority
Std Dev	Standard Deviation

Chapter One

Introduction

1. Introduction

We continue to co-exist in a technologically rich environment, many aspects of which are the practical result of addressing perceived needs, or solving problems. Solutions of this form did not rely solely upon problem solving approaches or knowledge from any one given area or discipline, but rather, are the results of problem solving that intelligently draws upon and integrates knowledge from a range of different areas in an ultimately synergistic manner. In its broadest sense, this thesis regards this as technological problem solving. Though it is recognised to exist in a number of contexts and on a number scales, this paradigm is arguably a fundamental, though often less recognised, feature of human activity. It is on a lesser scale, that pupils are able to engage with and develop this valuable form of problem solving through Technology Education.

1.1. Education & Technological Problem Solving

For a great many years, Technology Education in Scotland has occupied a minority area of the curriculum, yet the rich variety of authentic educational and experiential benefits it can afford pupils are significant and unique. Moreover, it is recognised that one of the dominant methods adopted in providing these is, indeed, problem solving. The notion of being a minority subject is reflected somewhat in its related field of research which, in spite of becoming ever more comprehensive, is still under-explored in comparison to other educational areas. Much of this is also because technology education is a relatively new subject area.

Though indeed new as a subject, several themes and findings are evident within the literature of the last 20 years or so. The more prominent of these include the nature of technological knowledge, technological literacy (Petrina, 2000), design education (Kimbell, 1982), pedagogical approaches in technology (Mawson, 2003), assessment approaches (Custer, 1996), curricular design (Zuga, 1986), subject perceptions (Jones & Carr, 1992), creativity (Lewis, 2009) and problem solving. Two salient points emerge from this. Firstly, virtually all of this research took place outside of Scotland. Secondly, while high quality solutions are critical, this research has generally shown that the most intriguing and potent aspects of pupils' technological thinking are revealed within the process of technological endeavour. In Scotland, however, this recognition is not widely reflected within classrooms and subjects are still largely delivered in an outcome driven fashion.

1.2. Technology Education & Scottish Curricular Change

This mismatch between theory and practice in Scottish Technology Education is particularly significant in view of the recent introduction of 'A Curriculum for Excellence'. The fact that this curricular model attempts to promote a more process-based approach to learning and teaching opens a pathway that provides a unique opportunity for research findings to more profitably align with practice in technology classrooms. In presenting key findings on the process of technological problem solving, this thesis makes a robust and valuable contribution that can inform changes within Scottish technology classrooms, and those around the world.

1.3. The Aim of this Study

Research associated with technological problem solving has been of notable quality, producing a range of significant findings. Though much of this is explored in the following chapter, studies have often focussed upon identifying features of pupils' technological problem solving activity, rather than if and how they characteristically differ between pupils. More recently, there has been an interest in the creative dimensions of solving more ill-defined problems. This thesis, however, aims to explore differences in problem solving approaches to more closed problems, and in relation to how successful task solutions are. Through doing so, factors associated with more and less successful technological problem solving are identified. Given the benefits and known importance of technological problem solving for pupils, such factors provide a basis upon which to directly inform instructional methodologies and pedagogy that help to enhance pupils overall technological capability. This aim is executed through a number of chapters, each of which is now described.

1.4. Overview of this Thesis

This thesis employs a largely qualitative, mixed-method design to identify and explore the differences in the technological problem solving activity between groups of pupils who produced good solutions, and those groups whose solutions were comparatively poorer. The core analytical approach shares much in common with the Grounded Theory Method (see Chapter 5). A cantilever bridge task is used to facilitate this investigation in conjunction with a variety of data gathering instruments including observation, questionnaires, semi-structured interviews, photographs and audio recording. Where necessary, bespoke analytical procedures are developed to aid this (see Chapter 5) and the subsequent data set provides a detailed and composite representation of the pupils' problem solving approaches. The two most contrasting groups are inductively analysed first to identify areas of key difference and a series of resultant analytical frameworks are then applied to ascertain the extent to which these differences are reflected in the activity of the remaining groups. Ultimately, important differences are shown to exist with regard to knowledge, process, social and study effects.

1.4.1. Chapter 2 – The Conceptual Framework

The conceptual framework reviews general findings from problem solving research and establishes a definition of classroom-based technological problem solving for the purposes of this study. The definition consists of three strands: 'problem solving modes', 'intellectual processes' and 'epistemology' which are developed successively within the chapter and synthesised at the end through an original conceptual model for technological problem solving. These strands reflect identifiable schools of thought within the associated literature. The first strand, 'problem solving modes', comprises four characteristically different modes of problem solving: Ill-structured problem solving, well-structured problem solving, emergent problem solving and troubleshooting. In each of these, a broad range of cognitive processes, forms and sources of knowledge are utilised and developed by pupils in technology classrooms. The aforementioned conceptual model is considered to describe problem solving activity in any of the four modes.

The scale of the conceptual model, range of processes and knowledge types it encompasses is such that it cannot feasibly be explored within a single study. Subsequently, this study focusses upon ascertaining where differences lie between higher and lower performing pupil groups using each of the three definitional strands as a basis for the investigation and findings. The research question stated at the beginning of Chapter 3 directly necessitates that differences between groups be explored by examining the use of intellectual processes and knowledge within one of the four identified modes. Due to a comparative lack of exploration within technology education research, the chosen mode is that of well-structured or well-defined problem solving and the task requires pupils to move from concept to physical solution.

1.4.2. Chapter 3 – The Epistemology of the Study

This chapter defines the research question and the epistemic stance adopted by this study in addressing it. The assertions and tenets of positivist and post-positivist approaches to inquiry are explored before defining the place of this study with regard to these paradigms. An epistemic rationale is developed which defines the study as naturalistic in nature and subscribing to a methodologically eclectic approach. Paramount to this are continued efforts to maximise the credibility and trustworthiness of the study.

1.4.3. Chapter 4 – Study Design & Data Gathering Methods

This chapter begins by describing the development a comprehensive sampling strategy which drew on a range of demographic and socio-economic data to ensure that a broadly representative sample was identified. In doing so, three S2 classes were identified with a maximum of 20 pupils per class which gave a total of 13 groups. The pupils were 12-14 years old. Following this, a pre-task unit of work was developed along with the main problem solving task; the former of which introduced pupils to the knowledge associated with the latter. In view of the grounded approach adopted herein, no attempts were made at this stage to ascertain if and where any differences lay, however, the unit and task were designed to encompass a maximal range of areas of the conceptual model. Two sets of data gathering instruments were then developed to build up a picture of ecological validity and describe the problem solving process. Two pilot studies that refined the structured observational tool were also undertaken as part of this.

1.4.4. Chapter 5 – Analytical Methods

This chapter consists of two sections. The first details the approach developed for identifying the four best solutions and four poorest solutions from the sample of thirteen groups. This involved a range of data sources including the use of a modified Delphi technique that established a good and poor cohort that were used within the main analysis of the study. The second section describes the development of a bespoke analytical method for exploring the photographic data of the developing solutions. This method was utilised to quantify a large portion of what was shown in each of the 228 photographs taken during the main study. This described the physical development of the groups' technological solutions.

1.4.5. Chapter 6 – Results & Analysis

This chapter reports on findings through four stages. Initially, data was analysed pertaining to the ecological consistency between participating classes. Following this, the group that produced the best and the group that produced the poorest solution from within each respective cohort were analysed to identify areas where differences lay. In the early stages, this process was highly inductive and lead to the development of three frameworks and a range of defined codes that were subsequently used to explore differences in each of the remaining cohorts. The final section reported the overall results for each cohort.

1.4.6. Chapter 7 – Discussion & Conclusions

This chapter lists the specific findings arising in the course of answering the research question in Chapter 3 and discusses the wider implications of each. It identifies the overall strengths and limitations of this study, possible future research that would augment the findings and makes recommendations for ways in which the findings can inform on approaches to teaching and learning.

Chapter Two

Conceptual Framework

2. Introduction

Rather than employ a traditional review of literature, this thesis draws upon research to develop a conceptual framework for technological problem solving in secondary school technology education classrooms. In doing so, technological problem solving is defined in terms of 'mode', 'intellectual processes' and 'epistemology', which are ultimately synthesised within an original conceptual model offered at the end. Though the interrelation between elements and considerations of these strands are complex, the chapter is presented in a number of distinct sections:

Section 1: Review of General Problem Solving Theory (Section 2.1)

Section 2: Problem Solving in Technology (Section 2.2)

Section 3: Modes of Technological Problem Solving (Section 2.3)

Section 4: Intellectual Processes of Technological Problem Solving (Section 2.4)

Section 5: Epistemology of Technological Problem Solving (Section 2.5)

Section 6: Sources of Knowledge for Technological Problem Solving (Section 2.6)

Section 7: A Conceptual Model of Technological Problem Solving (Section 2.7)

As described in Chapter 1, this thesis explores the differences between pupil groups that exhibit different levels of task performance. The mode, process and epistemological strands described in this chapter provide a lens through which forthcoming comparisons and investigation is undertaken.

By way of setting a provisional context, this thesis asserts that in Scottish technology education classrooms:

1. Problems tackled by pupils are numerous and range from well-defined to ill-defined.
2. Solutions pupils' produce can be conceptual or physical in nature.

2.1. Section 1: Review of General Problem Solving Theory

This section looks at how problems are defined and reviews the contributions of four prominent schools of thought: 'Behaviourism', 'Information Processing & Cognitive Psychology', 'Intelligence Theory' and 'Situated Cognition' as a backdrop to the development of a specific model for technological problem solving.

Problem solving is inextricably linked to human activity and ultimately, human existence. It is involved, to greater or lesser extents, in almost all facets of human endeavour and has thus received interest from a broad range of academic fields. Moreover, it is recognised that the nature of problems and how people approach solving them depends greatly upon the person, the context and domain within which they arise. It is firstly necessary, however, to consider how problems can be defined.

2.1.1. The Definition of a Problem

Over the years, many researchers have endeavoured to define the word 'problem' (*see* Duncker, 1935; Sheerer, 1963, Skinner, 1966; Newell & Simon, 1972). What is clear from these offerings is that a truly functional definition for what a problem is cannot be developed in isolation from considerations about the actions a person may undertake to solve a given 'problem'. For example, Hayes (1981) defines a general problem as "a gap someone is unable to bridge between where he or she currently is and where they want to be" (1981, pi). While this introduces the idea of an inability to progress from one stage to the next, it can be regarded as simplistic in that it assumes the solver knows where they want to be at any given point and, as such, is more applicable to what are termed 'well-structured' problems. This is true to a lesser extent in a definition presented by McCade (2000), drawing upon the work of Ritz et al (1986), who, in the context of technology, characterises a problem as 'a need that must be met', and here, it is possible to make a subtle distinction. Whilst there is still a suggestion of direction towards a desired state: insofar as a need has been identified, the definition does not imply that the solver knows necessarily where the desired state is, or in what manner it may be manifest. Frensch & Funke (1995), in exploring the European research on problem solving, build further on this and present a far greater distinction. Through exploring various definitions of 'problem solving', Frensch & Funke, characterise two different types of problem: that of 'implicit', and that of 'explicit' (p.18). Implicit problems are those in which solvers have good knowledge of what the solution will be like and also what must be applied in order to reach it: in many respects, these are not ‘true’ problems. Conversely, explicit problems are novel and complex in which potential solvers do not readily know what to do to get a solution or what form it may take. These definitions more clearly re-affirm that what constitutes a problem is inextricably linked to the prospective solver.

Despite this variance in definition, it is commonly agreed among psychologists, and others, that problems must possess, in one form or another, the following characteristics as described by Kahney (1993), and Mayer (1992):

3. *Givens*: This is what defines the current state of the problem and refers to all the available information about the problem at the initial state.
4. *Goals*: This is the terminal state of the problem and thinking is required to transform the problem from the given state to the goal state.
5. *Obstacles*: This refers to anything that impedes the thinker in gaining the goal state instantaneously. This may be information unknown to the thinker or processes that must be gone through to move towards the goal-state.

With this provisional definition in mind, the following sections will explore the understanding of human problem solving within the key fields of Behaviourism’, ‘Information Processing & Cognitive Psychology’, ‘Intelligence Theory’ and ‘Situated Cognition’.

2.1.2. Behaviourism & Problem Solving

As asserted by Homans (*in* Giddens, A. & Turner, J. Eds), Behaviourism was first conceived by J. B. Watson and significantly developed by B. F. Skinner (to ‘Radical Behaviourism’: *see* Overskeid, 1995); though not all forms of behaviourism stem from the work of Skinner (*see* Ormrod, 2008). Homans states the philosophical assumptions underlying behaviourist inquiry into learning were that greater progress could be made in psychology by studying people’s actions, and the relationships thereof, at observable points rather than trying to analyse consciousness and states of mind. From this arises the notion of behavioural re-enforcement. Skinner (1971), in an analogy between such operant conditioning and the contingencies of natural selection, argues that the environment and not the individual selects the behaviour and that occurrences thereof, are dependent upon positive or negative re-enforcement (*see also* ‘Phylogeny’ Skinner, 1953). Arguably, this is a very deterministic view of learning and almost entirely rejects the subjective consciousness of the individual (*see* Cohen, 1966). Three key theories that inform on problem solving can be identified within this behaviourist paradigm. Hardin (2002), cites both 'Trial and Error' and 'Hull's Response Hierarchy', while Skinner (1966) provides an account of problem solving as a behavioural act.

2.1.2.1. Trial & Error

'Trial and Error' is regarded by many to be one of the core mechanisms that underlie problem solving behaviour (Von Hipple & Katz, 2001) and is described by Hardin (2002) as "attacking the problem by various methods until a solution is found." (p.228) It has been observed that this form of problem solving is most overt with young children. Although applicable in situations as complex as high level chess games (Simon & Simon, 1962), Carpenter et al (1993), noted that, in a range of counter-sorting tasks, pre-school children engaged in trial and error strategies for task problems of a similar nature. Problems of a different nature did not appear to initiate trial and error. This notion of more or less favourable situations in which to undertake trial and error is reflected by Halasz & Moran (1983). They suggest that the problem solver can initiate trial-and-error strategies in situations in which they are less familiar; something Hipple also advocates when manufacturers develop products for clients who are unsure of exactly what they want. The main drawback to addressing a problem with this method, and a lack of knowledge about the nature of the solution, is that it is comparatively more time consuming (Salamatov, 1999).

2.1.2.2. Hull's Response Hierarchy

As argued by Hardin, 'Hull's Response Hierarchy' constitutes a second approach, which can be conceptualised as a blend of trial and error of learned responses. Originally termed the 'Habit-Family Hierarchy' (Hull, 1934), this dictates that an organism will first select the response that bears the strongest link to habit. Through a similar pattern to trial and error, a problem solver would hence apply a series of responses in order of habit strength until a solution is determined or no other responses are available. It is at this point that Skinner (1984) argues we must change the situation until a response occurs and, in doing so, defines problem solving as a behavioural act.

2.1.2.3. Problem Solving as a Behavioural Act

Problem solving as a behavioural act is characterised in detail through the operant analysis of problem solving (Skinner, 1966). Therein, it is argued that effective problem solving, beyond the time-consuming trial and error approach, utilises discriminative stimuli. In describing the problem of collecting a friends case from the airport without knowing what it looks like, Skinner argues that marking cases you find to be incorrect with chalk creates discriminative stimulus by altering the situation and re-enforce subsequent behaviour. Indeed, this manipulation of the environment is echoed in the considerations of intelligence theory and situated cognition.

2.1.3. Behaviourism & Classroom Problem Solving

Within classrooms, it is likely that this paradigm bears most relevance to situations where pupils have comparatively little knowledge about that to which the problem relates. In Technological Studies, for example, pupils may be required to trouble-shoot an ill-performing circuit or system. In the absence of a detailed knowledge about how the system operates, the approach may become distinctly behaviourist exhibiting trial-and-error, elimination and manipulation of the task environment to maximise the chance of isolating a solution.

The Behaviourist understanding based wholly on the observable aspects of learning, and subscribing to John Locke's notion of the mind as *tabula rasa* (*see* Winkler, 1996), makes no attempt to uncover the 'internal' mechanisms of problem solving. Contesting this prevailing view of the diminished role of thinking was a central force in shaping research into cognition.

2.1.4. Information Processing, Cognition & Problem Solving

These areas reflect the historical development in understanding about human thought. In contrast to Behaviourism, Regehr & Norman (1996) describe Cognitive Psychology as *"the objective study of how humans think"* (p.989) and that much of the initial understanding of problem solving in this field was centred on the computer metaphor of 'information processing'. Foundational to such work, however, is the conceptual structure and function of human memory.

2.1.4.1. The Structure & Function of Human Memory

Regehr & Norman (1996), describe the early information processing model of the mind as one in which information from the environment passes through 'perceptual memory' into 'short-term memory' and ultimately resides in long-term memory. Perceptual memory was thought to be large with a short retention time of around a second. Short-term memory was thought to retain information for around half a minute but was shown by Miller (1956), to be limited to 7 (+/- 2) chunks of meaningful information at a given time. It was also thought to be retained in an auditory signal where the act of remembering is facilitated by repeated verbalising in your mind. In contrast, long-term memory was seen as virtually unlimited in capacity and retention with information being stored semantically. There were, however, recognised challenges associated with retrieval.

Over time, inadequacies began to emerge with this model. Perceptual memory was modified to centralise the notion of a 'perception filter' allowing extraneous information to be mitigated on the basis of ascribed meaning (Johnson, 2007). The phrase 'short-term memory' was redefined by Baddeley (1986), as 'working memory' in response to considerable evidence that, rather than acting as just a temporary store, it was in fact the locus of mental processing. Further to this, recent research into the architecture of the prefrontal cortex suggests that, rather than the single pan-modal executive processor as seen in Baddeley's model, there are in fact numerous parallel executive memory 'cells' each of which contains the neural capability to both store and process information (Goldman-Rakic, 2000). Estes (1982) also recognises the fact that long-term memory has been re-conceptualised as a composition of episodic memory (what) and semantic memory (how), though Regehr & Norman argue these are often difficult to distinguish between in real performance. From within, and parallel to, this path of development arose the 'Information-Processing Theory of Human Problem Solving' (Newell & Simon, 1970).

2.1.4.2. The Theory of Human Problem Solving

The first shift away from the behaviourist S-R paradigm is the 'Test-Operate-Test-Exit' algorithm proposed by Miller (1960). Herein, Miller shows that an action is carried out, evaluated and modified cyclically until a goal is achieved or the endeavour is abandoned and can be seen as an influential precursor to the work of Newell & Simon. The theory of human problem solving seeks to describe such behaviour in terms of memory operations, rules and control processes and is normally tested and validated using computer simulations. In establishing a set of core processes, it is proposed that individuals can successively employ means-ends-analysis to solve problems within a mental problem space. The structure of the task environment determines the structure of the problem space, which, in turn, determines the possible operations and rules that can be applied towards a solution.

This theory was developed and tested using highly structured and controlled problem tasks that now form the basis of wider criticism and recognition of limitations in less abstract problem situations (see Discussion on 'Situated Cognition'). A study by Schraw et al (1995), examines this very concept through empirical testing of Kitchener's Model of Hierarchical Cognitive Processing (shown in Table 2.1).

Three-Level Model of Cognitive Processing	
Level 1	Inferential rules and strategies
Level 2	Metacognition and monitoring
Level 3	Monitoring of epistemic nature of problem

Table 2.1

Schraw et al, confirm Kitchener's assertions through evidence that well-structured problems can be solved using levels 1 and 2, whilst ill-structured problems can only be solved through engaging with level three. This supports the difficulties observed in applying the Information Processing model to ill-defined problems and suggests that it is best suited to understanding the behaviour of pupils engaging in well-structured tasks. A thesis by Doherty (1999) successfully explores the relationship between information processing factors, such as working memory capacity and problem demand, for pupils solving mechanisms problems in technology classes. However, the aforementioned evidence suggests information processing to be insufficient in accounting for pupils' engagement with more creative problem solving tasks.

2.1.5. Intelligence Theory & Problem Solving

Intelligence has, for many years, been of great interest to the educational community. Indeed, Snow & Yalow (1982), argue that despite the fact that education and intelligence have often been conceptualised independently, each is fundamentally a product of the other (p. 493). This assertion is shared by Martinez (2000), who, in his book 'Education as the Cultivation of Intelligence', explores theories of 'learnable intelligence' (p. 57, 173).

Learnable intelligence can therefore be seen as intrinsically tied to thinking, which Johnson (1982) defines as problem solving in and of itself. This multifaceted overlapping of conception is reflected in a statement by Sternberg (1982), who comments that *"reasoning, problem solving and intelligence are so closely interrelated that it is often difficult to tell them apart"* (p.225). From within this myriad of constructs, however, 'Problem Solving' is seen to form a common core element of both lay and professional definitions of intelligence.

Conceptions of Intelligence have developed over time from a unitary, measurable construct of intellectual capacity inferring the complexity of problem solving an individual could undertake (*see* Spearman, 1904), through to componential (*see* Sternberg, 1980), multiple (*see* Gardner, 1995) and emergent models (*see* Martinez, 2000). From within this rich line of development, salient contributions to the understanding of problem solving from 'Fluid & Crystallised Intelligence' and 'Componential Intelligence' are explored.

2.1.5.1. Fluid & Crystallised Intelligence

The notion of 'fluid' and 'crystallised' forms of intelligence is first proposed by Cattell (1963) as an early shift away from a singular intelligence construct' 'G', set forth by Spearman (1904). Fluid Intelligence, G*f*, represents biological influences on intelligence, is not considered to be domain specific and is often recognised as an individual's ability to succeed in novel and complex environments. Crystallised Intelligence, G*c*, represents the cultural and educational influences on intelligence and is manifest in more domain-specific ways. Arguably, G*f* relates most closely to solving in genuinely problematic situations, such as the explicit problems defined by Frensch & Funke (1995).

As an inherent human ability, G*f* is understood as a key source of differences in performance between people's reasoning and complex problem solving (Gray et al, 2003) and, in contrast to G*c*, is shown to decline with age (Horn & Cattell, 1967). Engle et al (1999), propose that it is linked closely to working memory and that these two factors determine how long problem solvers can keep mental representations active in the face of external and 'attentional' interference. Moreover, fMRI (Functional Magnetic Resonance Imaging) has shown the lateral prefrontal cortex to mediate the relation between G*f* and performance in working memory tasks suggesting an empirical neurobiological basis. Until recently, however, and notwithstanding ageing effects, G*f* was regarded as fairly fixed for an individual, with a strong hereditary component (Cattell, 1963). Consciously improving G*f* is challenging due to the fact that it relates to novel problem situations and practising such situations would necessarily diminish the novelty and engender different cognitive processing. Furthermore, people can find it extremely challenging to transfer learnt performance to new tasks (Healy et al, 2006). That being said, a controlled study by Jaeggi et al (2008), demonstrates that training individuals with a highly demanding n-back[1] working memory task over a period of four weeks results in a striking transfer effect and notable increase in G*f*. This sits in contrast to the widely documented transfer difficulties in other studies (e.g. Detterman, 1993).

Two key points arise from this in considering pupil activity within technology classrooms. Firstly, the degree to which pupils may engage with dimensions of fluid intelligence will likely depend upon the authenticity of the problem, how it is presented and how they understand its internal structure. It is likely that many of those problems most novel to pupils are also ill-structured. Secondly, in addressing such problems, it could be argued that a pupil's ability may be somewhat predetermined, although the recent study by Jaeggi et al (2008), would suggest it may be possible, under specific circumstances, to develop approaches that enhance this. It is also recognised that this concept is still in its infancy.

2.1.5.2. Componential Intelligence

Despite there being numerous conceptions of intelligence that are componential, this focuses on the work of Robert J. Sternberg. In developing the theory of Triarchic (Sternberg, 1984) and then Successful Intelligence (Sternberg, 1999), Sternberg identifies a range of 'components' that underlie intelligent behaviour. This work shares its psychological basis with information processing and Sternberg defines such components as 'information processes' that act upon the internal representations of objects or symbols (Sternberg, 2006). Each of these has the independent properties of 'duration', 'difficulty' and 'probability of execution'. Although five groups of components are defined (meta, performance, acquisition, retention and transfer), it is within the meta-components that he identifies six processes seen as complicit in human problem solving activity. These are described as follows:

[1] N-back tests are widely used within cognitive science and cognitive neuroscience as a means of measuring and training dimensions of short-term memory. Subjects are given a sequence of stimuli and are required to correctly recognise when the current stimuli matches the conditions of one or more previously seen within the sequence.

- Selection of performance components for task solution
- Selection of one or more representations upon which these components will act
- Selection of a strategy to combine components
- Decision about maintaining a given strategy
- Selection of a speed-accuracy trade-off
- Solution monitoring

In exploring these meta-components against examples of ill and well-structured problem solving Sternberg demonstrates that there are differences in those which are drawn upon depending on the nature of the problem being addressed.

2.1.6. Situated Cognition & Problem Solving

In contrast to those paradigms with their bases in information processing, Clancey (1995), describes the situated perspective as one that views human knowledge as a capacity to coordinate and sequence behaviour and adapt to changing circumstances; quite unlike semantic networks in computer programs (*see also* Lave & Wenger, 1991). More specifically, Robbins & Aydede (2009), state that situated cognition is defined by three theses: 'Embodiment', 'Embedding' and 'Extension'. Embodiment argues that cognition is dependent upon the body as well as the mind; embedding asserts that cognitive activity exploits the structures found within nature and the social environment, whilst extension recognises that the boundaries of cognition move outside the individual organism. This paradigm subsequently views cognition and thinking from a distinct and more anthropological basis than more traditional conceptions (Schnell & Black, 1997). It is one that views it as intimately tied to the context and environment in which it takes place (*see* Brown et al, 1989) and, through doing so, can account for some of the shortfalls in regard to ill-structured problems identified within classical information-processing theory. This being said, it does not have its own theory of problem solving to date.

Within situated cognition, problem solving is not seen as distinct from other types of reasoning and is hence not investigated discretely. Whilst acknowledging that current research is far from sufficient to allow for this, Kirsh (2009), argues that a situated theory of problem solving would be one of interaction that could encompass four dimensions: 'Hints', 'Affordances', 'Thinking with Things' and 'Self-Cueing'. Each of these is described as follows:

Dimension 1: Hints

These are considered verbal and non-verbal cues that act as a heuristic bias on search strategies. Though the information-processing notion of the search as a key determinant of problem solving behaviour is played down by situated cognition, this is a point of commonality. Through reference to classroom examples, Kirsh argues that hints in the form of cues are tied to candidate generation and evaluation.

Dimension 2: Affordances

These are defined as dispositional properties of objects and environments that allow for interaction and performance of actions. An affordance of a handle, for example, may be that it is 'pullable'. It is asserted that people will discover possible ways forward through interacting with the environment through a series of affordances and constraints but that these may or may not be recognised depending on the cues that arise during the activity. A skilled solver, for example, would identify affordances most immediate to a solution but it may be that affordances are not obvious and hidden by context.

Dimension 3: Thinking with Things

This accounts for people's use of artefacts, resources and tools to help them during the thinking process. In a sense, it can be seen to distribute cognition across internal and external representations and ties thinking to the way we encounter the world. A similar, but not identical, phenomenon is observed when sketching.

Dimension 4: Self-Cueing

This shares a significant similarity to the idea of meta-cognition and involves people re-arranging the environment to stimulate new ideas when candidate generation begins to slow down. A familiar example cited by Kirsh, is the process of re-arranging scrabble tiles to better facilitate the formation of new words (similar to 'Discriminative Stimuli'; Skinner, 1966).

Although in its infancy with specific regard to problem solving, this arguably reflects the nature of practical problem solving within technology classrooms more closely than the other paradigms. Centralising the interaction between the solver and the physical environment directly accounts for fact that pupils often produce tangible, physical products and that, even in instances where the solution is a written, conceptual one, there have likely been additional physical resources and tools utilised in arriving there.

Having discussed some of the major contributions to problem solving theory, the following section develops a conceptual framework of classroom-based technological problem solving for use within this study.

2.2. Section 2 – Problem Solving in Technology

This section explores some of the underlying considerations associated with a definition of technological problem solving, at the end of which, a three strand framework for developing the definition is presented consisting of 'Mode', 'Process' and 'Epistemology'.

It is firstly necessary to make the definition distinction between solving problem *through* technology and solving problems *in* technology. The former can be seen as domain-general as is recognised in a profusion of disciplines and domains. A company may, for example, purchase a photocopier to solve the problem of having to produce hundreds of copies of the same thing. In this sense, the technology is both applied and exists as a tool. This is accounted for by Kornwachs (1998) who identifies technology as a metaphor. Under this paradigm, Rapp (1999) argues that technological artefacts serve to extend the natural capacities of humans in much the same way as a telephone extends the distance over which we can naturally communicate. In this capacity, employing the technology is not necessarily dependent upon knowledge of how it works or how it was developed, but is necessarily dependent upon knowledge of its function and how to use it. This is recognised and prevalent in virtually all aspects of society, from homes, and places of work to hobbies such as gardening. What makes solving problems through technology distinct from solving problems in technology is that the nature of the associated knowledge and the fact that the technology itself is not the focus of the problem solving endeavour.

In view of technology within secondary classrooms, the framework developed within this thesis shall pertain to problem solving *in*, rather than *through*, technology.

2.2.1. Defining the Intellectual Domain of Technology

Before consideration can be given to the detail of problem solving in technology education, it is necessary to define the intellectual domain of technology. It is recognised that there is continuing discourse regarding whether or not there is, in-fact, an 'intellectual domain' of technology. Waetjen (1993), argues that technology does not have an intellectual domain as it is void of a structured body of knowledge, of organising concepts, of underlying ideas and fundamental principles that define it as an academic discipline (p.8). In many senses, Waetjen is correct, and there are arguably two main strands to the legitimacy of his arguments. The first is when technology is considered in a wider, more societal context, and the second is when technology is compared to other, more readily identifiable domains such as mathematics or science, that exhibit notable constancy over time and place.

Hence, in terms of its commodities, the nature of technology is very different. However, with regard to secondary school education, the very fact that defined technology curricula exist, suggests there is an intellectual domain in this context; albeit, dissimilar in nature to others and possibly not yet fully understood. Thus, while Waetjen's assertions are logical, it can be argued that the extent to which technology has an intellectual domain depends principally upon on what constitutes a 'domain'. For the purposes of this thesis, a generic domain is recognised as 'a sphere of activity, concern, or function' (Dictionary of the English Language, 2000). In regard to technology, through a critical evaluation of 'technological knowledge', Custer (1995), defines said knowledge as 'knowledge of accumulated practice' where 'activity' is a central component. Moreover, he subsequently maintains that the only truly distinguishing feature between technological problem solving and other types of problem solving, is the 'goal thrust'; the creation of physical artefacts. This recognises 'activity' as intrinsic within technology and henceforth satisfies the use of the term domain, further argued as 'unique' by virtue of its aforementioned goal thrust. Here, the precursory term 'intellectual' is taken to pertain to pupils' intellectual skills, abilities and knowledge, which are shown throughout this thesis to be fundamental to, and characteristic of, technological activity.

It is on this foundation, and the fundamental arguments articulated by Custer, that problem solving within technology education is explored.

2.2.2. Problem Solving within the Intellectual Domain of Technology

Employing generic problem solving strategies within the intellectual domain of technology to generate solutions constitutes the second interpretation of 'technological problem solving'. The use of the term 'generic' arises from evidence that many of the strategies or processes employed within technological problem solving bear great cognitive and psychological similarity to those employed in other fields such as counselling (Custer, 1995). Consequently, the scope of this definition need not be limited to problems that are identified within the domain of technology, but rather pertain to solutions that are arrived at within the domain of technology. An example of this may be the design and construction of a bridge to allow travel across a body of water, or the development of a more modern system that controls a robot in a production line with improved efficiency. Through both of these examples, certain aspects of the problem solving process become apparent, including the fact that the solution to each is 'technological' in nature, and furthermore, that the solutions are physical rather than conceptual (Custer, 1995).

When analysed, it can be argued that there are three basic stages to each of the aforementioned examples. Firstly, there is an identified need, desire or want, which it is hoped that the appropriate application of problem solving processes and knowledge will meet. As has been demonstrated, this need may lie within or outside the sphere of technological activity. Secondly, general problem solving processes and heuristics are applied to move toward a solution (*see* Kahney, 1993; Mayer, 1992). Within the information-processing model, this is accounted for, and takes place, within the 'problem space' (Newell & Simon, 1973). Here, the term 'resources' is used to refer to all that is brought to bear upon the solution to the problem including those that are physical, psychological and knowledge-based. In applying problem solving processes, the inferences constructed by the solver leads them to draw on specific areas of knowledge, now conducive to the problem in hand. Thirdly, there is a solution, which is, to a large degree, 'technological' in nature due to the fact it physically embodies the application of the problem solving processes and related knowledge. It is hence sufficient to conclude that it is the physicality of the solution or artefact that defines its conceiving process as technological. This distinction was argued by Custer (1995), who sets this within the context of three separate types of problem solving, between which, 'goal thrust' is the distinguishing factor. These are described in Table 2.2.

Types of Problem Solving Adapted from Custer (1995)	
Type of Problem Solving Space	**Goal Thrust**
1. Technological	Artefacts *(including physical, human-made objects as well as programs which drive physical objects)*
2. Social/Personal	Healthy, efficient, satisfying, meaningful, interpersonal and intrapersonal relationships *(including cultures and nations)*
3. Natural/Ecological	Understanding of the natural world and homeostasis *(between humans and environments, between human-made artefacts and the natural world and within the natural world)*

Table 2.2

It is within the context of the technological problem space that this thesis is set.

2.2.3. Technological Problem Solving

In considering Technology Education, Custer et al (2001), describes 'problem solving' as a critical thinking skill necessary for addressing issues related to technology and for developing effective solutions to practical problems (p.5). Moreover, problem solving has been identified by many as the 'central method' in learning about, and gaining understanding of, technology (Savage & Sterry, 1990). Importantly, technological problem solving, here, defined as problem solving within the intellectual domain of technology, is widely recognised as a necessary skill and intellectual process in modern society (*see* Johnson, 1987; Waetjin, 1989; McCade, 1990).

Whilst the definition provided by Custer et al (2001), draws attention to technological problem solving as a thinking skill, it can be argued that the nature of the thinking executed within the solving process is shaped to a large extent by the problem itself. As discussed by Frensch & Funke (1995), simple problems would require less time and effort than very complex problems would (p.18). As will be demonstrated through the following exploration, technological problem solving is no different in that it is a dynamic process that may involve simple, as well as 'complex' strategies and thinking. Frensch & Funke (1995), after an analysis of definitions from leading problem solving researchers, provide what they term an 'integrated' definition of complex problem solving:

> *"Complex problem solving occurs to overcome barriers between a given state and a desired goal state by means of behavioural and/or cognitive, multistep activities. The given state, goal state and barriers between the given state and goal state are complex, change dynamically during problem solving and are intransparent. The exact properties of the given state, goal state and barriers are unknown to the solver at the outset. Complex problem solving implies the efficient interaction between a solver and the situational requirements of the task, and involves a solver's cognitive, emotional, personal and social abilities and knowledge."*
>
> (p.18)

Although not all technological problem solving is complex, this comprehensive definition comprises many features, circumstances and requirements that bear relevance.

2.2.4. A Rationale for Technological Problem Solving

From the preceding discussion, the following six-point rationale is adopted as a basis on which to define ‘technological problem solving’ for a study in secondary school technology education:

1. Technology constitutes both the focus of learning and, as necessary, an adopted tool that enhances human capacity.
2. Although case specific, the knowledge associated with technology as a tool in problem solving can be different in nature from that associated with it when it constitutes a focus of problem solving.
3. The ‘intellectual domain’ in which this problem solving takes place is shaped ‘curricularly’ and by activity and ‘knowledge of accumulated practice’, rather than a structured and organised body of knowledge and concepts as found in domains such as mathematics.
4. Problems have identifiable givens, goals and obstacles and the complexity of the problem solving process is linked with how well these are understood and addressed by the solver at given points in time.
5. The strategies and processes drawn upon are not unique to technological problem solving and share similarity with those found in other, non-technological, forms.
6. The results of technological problem solving endeavours are always manifest in a physical form.

The salient aspects underpinning all criteria in this rationale are either that of ‘knowledge’ or ‘process’. As such, these will form two essential strands of technological problem solving. However, after and through a review of literature, it is the intention of this thesis to formulate a specific definition using a three-strand framework via the addition of ‘Mode’. The framework developed for defining technological problem solving is shown below in Table 2.3.

The remaining sections of this chapter develop and characterise technological problem solving through an exploration of each of the strands in this framework.

A Framework for Defining Technological Problem Solving	
Strand	**Description**
1. Modes of Problem Solving	This relates to the types of problem solving that can be identified within technology education classrooms.
2. Intellectual Processes	This relates to the cognition and intellectual activity employed by pupils during technological problem solving.
3. Epistemology	This relates to the types and structure of knowledge drawn on by pupils during technological problem solving.

Table 2.3

2.3. Section 3 – Modes of Technological Problem Solving

This section discusses 'Modes of Technological Problem Solving'; the first strand of the definition of technological problem solving. Ultimately, four modes are established: ill-defined, well-defined, emergent problem solving and troubleshooting.

With regard to technology education, Hill (1997), highlights the fact that the task of solving a problem can be approached in a variety of ways on a continuum from simple trial and error to very complex. This statement can be seen to echo the distinctions made by Frensch & Funke (1995). In provisionally considering this, it is not unjustified to assume that the type of problem, and the manner in which it is understood by a potential solver, will affect the nature and type of problem solving processes employed (Welch & Lim, 1998; Kahney 1993). Building on the aforementioned work in defining a problem, Mayer (1992), draws upon the work of Reitman (1956), who demonstrates that problems can be categorised into four groups dependent upon how well specified the given and goal states are:

1. *Well-defined given state and well-defined goal state*: 'How can you turn a sow's ear into a silk purse?' A clear starting point and a clear ending point, although often offers little to inform on how it may be solved.
2. *Well-defined given state and poorly defined goal state*: 'How can this Ford engine be redesigned to improve the gas mileage?' Provides a clear starting point but could result in a number of 'suitable' solutions.
3. *Poorly defined given state and well-defined goal state*: 'Explain the mechanism responsible for sun spots.' The goal is clear, but the initial state that causes the goal is not.

4. *Poorly defined given state and poorly defined goal state*: 'What is red and goes put-put?' A vast number of solutions would satisfy this problem.

Indeed, problems within technology education can be described using Reitman's categories, and are often referred to as well-structured or ill-structured problems depending on the information provided for each state. With regard to poorly defined and well-defined goal states, Twyford & Järvinen (2000), provide a model, shown in Figure 2.1, which illustrates the way in which arising activity is respectively shaped when pupils engage in 'technological' problem solving.

The most distinctive aspects of this model suggest that the type of problem can largely determine social interaction and the use of knowledge by pupils during problem solving. According to this model, the more 'open' the problem is, the more similarities can be seen to exist with the complex problem solving defined by Frensch & Funke (1995); most starkly, this is with regard to the solvers' personal & social knowledge and abilities.

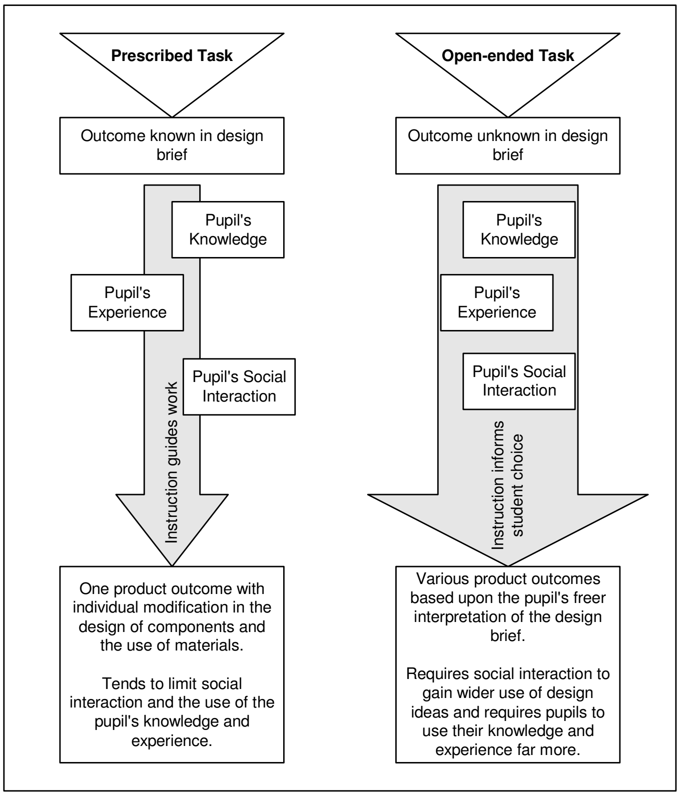


Figure 2.1 – Relationship between Task Type & Nature of Activity

However, McCormick (1996), in examining problem solving processes and types of problems, presents an alternative breakdown:

1. A general problem solving approach referring to the process more than the problem itself
2. A global problem referring to a significant problem, the solution to which will take some time
3. Emergent problems that arise throughout any process and must be overcome in order to proceed.

Here, McCormick (1996), describes distinct generic approaches that can be applied regardless of the context, as well as problem scale, and, in doing so, introduces the notion that additional, smaller problems arise within the course of seeking a solution. This, however, provides only general characteristics. McCade (1990), presents a more detailed analysis of technological problem solving. McCade argues that one of the key concerns regarding the 'technological methods' is that "many authors and educators consider problem solving only from the perspective of design." (p.1) He contends this is too narrow and simplistic a point of view and advocates that there are three distinct modes of technological problem-solving: (a) design, (b) troubleshooting and (c) technology assessment (or impact evaluation) (p.2). The basic characteristics attributed to each of these modes are summarised below in Table 2.4.

Modes of Technological Problem Solving Defined by McCade		
Mode	**Defined As**	**Characteristics**
1. Design	Proactive Problem Solving	Involves refinement of original concept, research experimentation and development in preparation for production. Closely linked to innovation and creativity.
2. Trouble Shooting	Reactive Problem Solving	Involves finding and correcting problems during the production or utilisation of technical solutions. Involves a realisation that there is more to technology than innovation.
3. Technology Assessment	Critical Analysis	The critical analysis of the impacts of technical solutions in order to predict possible outcomes and choose the most appropriate solutions to problems.

Table 2.4

Each of the modes defined in the above table are critically explored in the following sections.

2.3.1. Design as Technological Problem Solving

Indeed, McCade's notion that design constitutes a form of technological problem solving is strongly accepted within research literature and is employed throughout most schools (*see* Denton, 1993). It is widely accepted as the predominant method of 'open-ended' problem solving in technology education (McCade, 1990). The notion of 'open-ended' constitutes a definitional prerequisite according to Williams (2000b), who states that the term 'problem solving' within technology education differs from 'design' in that design deals with ill-defined problems, and may not even begin with a problem, whilst 'problem solving' *per se*, necessarily does. The ITEA (2000), recognise design as one of the five major organisers of technology education. Similarly, it is defined under the 'Technological Creativity' aspect of technological capability as defined for Scottish Technology Education (SCCC, 1996). Denton (1993), argues the importance of design as a tool by which pupils can develop outcomes of various types, an assertion that is echoed by Williams (2000a). He comments on the importance of the cognitive skills pupils stand to develop through engagement with design. Furthermore, he argues that these significant skills can be properly addressed only within the context of technology education, where ideas can be developed and tested in a practical manner. The fact that here, ideas are linked to practical activity is consistent with the rationale for technological problem solving herein. Design, though often employed and referred to as a problem solving method (McCade, 1990; Denton, 1993), need not always stem from a problem in the truest sense of the word, but rather, can be employed to address a need or want (*see* Williams 2000b; Flowers, 1998).

Despite the fact that there are variations of the design process, it is often presented as a series of stages and has its basis in the general problem solving method. Layton (1993), provides a general problem solving model as well as a model for scientific and technological/design based problem solving. Table 2.5 presents these in such a way as to highlight the differing nature of analogous stages in the process.

In effect, this constitutes a methodology that can be learned and applied in order to solve various problems (Williams, 2000a). In the technology model, the first two stages can be seen as those in which solvers build up knowledge and understanding of the demands and challenges of the problem situation. The formulation of ideas and manufacture constitutes a more creative phase, and the testing is more reflective and evaluative in nature. There are, however, two main concerns associated with this notion of 'stages'.

Stage-Based Analogy between Domain Specific Problem Solving Processes		
General Model for Problem Solving	**Scientific Process**	**Technology/Design**
Understand the process	Consider the natural phenomenon	Determine the need
Describe the problem	Describe the problem	Describe the need
Consider alternative solutions	Suggest hypotheses	Formulate ideas
Choose one solution	Select one hypothesis	Select one idea
Take action	Experiment	Make product
Evaluate the product	Does result fit hypothesis	Test product

Table 2.5

Firstly, there is debate regarding the 'generalisability' of problem solving skills between contexts and secondly, the apparent discontinuity between the algorithmic process presumed by the design approach and the cognitive activity and strategies of pupils during 'freer' designing.

With regard to 'generalisability', Liddament (1996), highlights concerns surrounding such high-level skills as problem solving. He firstly argues that the 'generalisability thesis' has both a stronger and weaker form, the former of which claims that problem solving processes can be taught discretely and independently from context (p.2). In acknowledging the arguably post-positivist paradigm that dictates these skills are not independent from context, Liddament recognises the latter form as more plausible. He claims that although skills learned in one context may be applied in others (e.g. differential calculus), to be successful within technology education, it requires the 'intelligent' application of skills rather than the 'algorithmic' application of skills. In effect, this can be seen as recognition of an 'enculturated' view of learning, such as that asserted within Situated Cognition. This paradigm of learning argues that aspects of that which is learnt remain closely tied to the situation and environment in which the learning takes place (*see* Brown et al, 1989; Clancey, 1995; Schell & Black, 1997; Bredo, 1994). Of central importance to technological problem solving is the fact that research in this field strongly suggests that pupils often find it challenging to shift their understanding between contexts. Significantly, this author argues this shift to be the raison d'etre of technological problem solving in which understanding in a conceptual context is ultimately manifest in a physical one. Whilst the significance of context is discussed by McCormick (1996) and others, it is starkly demonstrated by Catrambone & Holyoak (1989), who, through a series of five experiments testing transfer in analogue problems, show that the biggest factor affecting vastly reduced performance is changing context; even over and above things such as the passage of time.

These arguments levelled by Liddament (1996), and further discussed by others (*see* Flowers, 1998; McCade, 2000; Welch & Lim, 2000), are, in some ways, closely linked to concerns surrounding the identified discontinuity. Conclusions from empirical studies indicate a significant dissimilarity between the sequential linearity implied by the design process and the manner in which pupils produce solutions when designing. Mioduser & Kipperman (2001), argue that this disparity and the overly structured approach to design represent the source of many learning and motivational difficulties in design-based activities (p.3). Norman & Roberts (1992), in examining the model used within the English Technology Curriculum, suggest the force behind this is assessment requirements rather than recognition of the 'nature' of design. In addition, Liddament (1996), argues that the systematisation of designing is very much a pedagogical creation spurred by the explicability of structure and order. Moreover, the conclusions from an empirical study of the strategic thinking of untutored designers by Welch & Lim (2000), adds credence to this tension. They concluded that novice designers:

- Sequence the sub-processes of designing quite differently from the prescribed models
- Do not generate several possible solutions and choose the most effective
- Make greater use of three-dimensional modelling
- Make less use of two-dimensional modelling than that suggested by the text books
- Constantly evaluate their design proposal from the earliest moments of the design and make process (confirmed by Mioduser & Kipperman, 2000)

Williams (2000a), concurs with this and further argues that the sequencing and standardisation of processes neither reveals nor encourages cognitive development as pupils are forced into a way of thinking that is predetermined by the teacher (p.52). Jones (1997), argues that pupils who simply move through the stages of the process do not solve problems as well and fail to engage in proper reflection. Whilst there are clearly implications set forth within these arguments, this author does not agree that sequencing and standardisation bestow as starkly negative an influence on cognitive development as suggested. A more balanced view must take cognisance of the degree to which pupils can self-navigate through the type of large and open-ended problem phases that exist when designing. Whilst it is noted that there is less comparative literature evaluating the potential gains that a pupil may make from a degree of structure and sequence, there is both necessity and benefit found in discussion from van Niekerk et al (2008) and Kimbell (1986), respectively. As part of the foundation of his book exploring Design Education, Kimbell presents a graph of the changing capacity of pupils to undertake independent design thinking, shown in Figure 2.2.

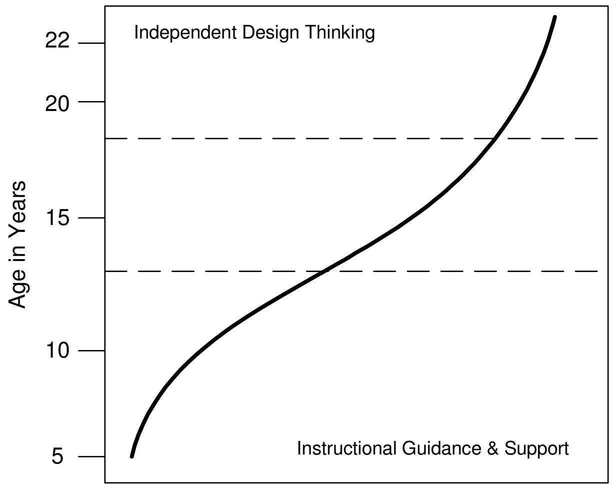


Figure 2.2 – Age vs. Pupil Independence in Design Thinking

This suggests that, even with the greatest of intentions, it is unlikely that, in completely removing imposed sequence and structure, pupils would be able to navigate through the problem effectively. This is strongly echoed in comments by van Niekerk et al (2008), who employs a 10-stage design process in a study developing a process-based assessment framework for technology. Here, he argues a balance to be necessary; too little structure to the process can "lead to a sense of helplessness in learners with the possibility that knowledge and skills are not adequately developed", but also acknowledges that over-structured and prescribed processes can inhibit creativity (see Compton & Harwood, 2003). Indeed, Williams (2000a), in concurrence with Denton (1993), asserts that the very purpose of carrying out design tasks is to provide a vehicle through which pupils can develop other competencies such as independence in problem solving, creativity, ability to be critical, expressive and reflective (*see* Paterson et al, 1981; Webb, 1982 and Maybin, 1994, for more discussion of reflection). This echoes the earlier characteristics of design presented by McCade (2000), and reiterates that design activity demands many higher-cognitive skills and is often closely linked with creativity (*see* SCCC, 1996).

2.3.1.1. Creativity in Design

One of the key features promoted through design and successfully addressing open-ended problems is creative activity. Though creativity, in a range of forms, can be identifiable at various stages of the design process; it is most prominent during the generation of ideas. As described earlier, Layton (1993), presents a basic stage-based model for progressing through a design and make problem in technology education. Figure 2.3, analyses the nature of each of these and identifies this more creative stage. This is concurrent with Wong & Siu (2011) who assert that the design process is a global framework within which creative activity forms a sub-set.

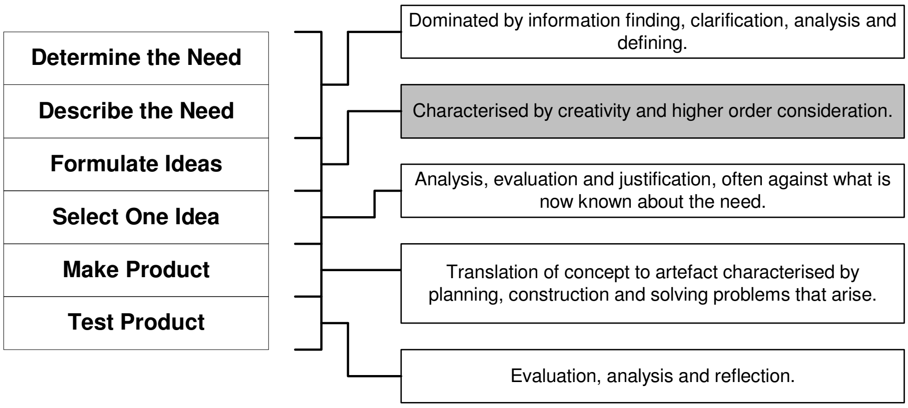


Figure 2.3 – Analysis of Stages in the Design Process highlighting Creativity

Attempts to understand the rather complex and nebulous concept of creativity span a great many years. Isaksen (1987), asserts that creativity should be viewed as a 'multifaceted phenomenon rather than a single unitary construct capable of precise definition'. This is reflected in the dichotomy of creativity in the work of Williams et al (2010), wherein it is argued that a 'romanticist' view, and an opposing 'rationalist' view, have accrued notable historical prominence, the former from as early as Plato. In this paradigm, creative acts evolve spiritually from the irrational unconscious and rational thought interferes with this process. Conversely, the rationalist paradigm sees creativity as arising from a conscious, deliberating and intelligent mind. Although not opposed in exactly the same fashion, Davies (1996a), explores two characteristically contrasting dimensions of creativity: (a) the exercise of 'intellect' (concern for cognitive aspects including mental modelling), and (b) the exercise of 'intuition' (concern for imaginative, emotive and motivational aspects). He further contends that design requires a "creative leap" in order to arrive at a solution to ill-structured problems. Educationally, Williams et al (2010), argue that the rationalist view is more significant in that it suggests creativity can be taught or developed.

2.3.1.2. Theories of Creativity

The role of creativity in education continues to be explored extensively, and contemporary thinking appears largely characteristic of rationalism. It is against this somewhat skewed symbiosis that the following section explores contributions made by three key thinkers: Runco, Sternberg, and Csikszentmihalyi. These contributions, and their arising implications, are considered in relation to design and technology education.

Mark A. Runco

Runco (2007), provided an all-encompassing discussion of thinking on creativity from which three areas of significance arise: threshold theory, stage models and componential models of creativity. Firstly, Runco describes '*Threshold Theory*' which accounts for a relationship that seems to exist between creative potential and intelligence. It does not consider them to be synonymous, nevertheless, from a strong empirical foundation; it suggests that there is a level of intelligence below which creative behaviour is very unlikely to occur. The idea that intelligence and creativity are in some way related is heavily reflected in the body of work of theorists such as Robert Sternberg and Howard Gardner.

Secondly, Runco identifies 'Stage Models' and 'Componential Models' of creativity from within the literature. In the former, he cites Waller (1926) who offers a four-stage model of a creative act in which preparation, incubation, illumination and verification occur successively; not dissimilar to the more global 'linear' stages of design and technological problem solving. Waller states that 'preparation' involves problem identification and information gathering. 'Incubation' accounts for a period of sub-conscious cognitive processing and is common to most models of creativity; 'free from the censorship of the conscious mind' (Runco, 2007). This can involve processes such as synthesising the opposing thesis and antithesis into a resultant compromise; something that children are unable to do until late adolescence. 'Illumination' is synonymous with 'insight', and characterised as a singular occurrence that is quick and spontaneous (eureka moment), sitting in contrast to the process of trial and error. 'Verification' allows refinement through testing and evaluation.

In contrast, componential models of creativity are more prolific and posit no such sequential structure. Instead, they set forth a variety of attributes, requirements and influences that the creative thinker reacts to and processes as demanded by the situation. Runco & Chand (1995) set forth their own two-tiered componential model. The first tier accounts for influences on the creativity process such as motivation and knowledge, the former of which is a necessity. The second tier accounts for problem finding skills, ideation and evaluation. It is argued that flexibility in cognitive style and thought is central to creativity in the second tier. This model bears some similarity to that offered by Sternberg (2006).

Robert J. Sternberg

Sternberg (2006), through extensive work over a 25-year period, presents what is termed an 'Investment Theory of Creativity' that arose from his work on human intelligence. Sternberg argues that in order to be creative, one requires confluence of six 'resources' upon which people can draw. These are listed and described in Table 2.6 and, collectively, have also been empirically shown to predict creative performance.

Sternberg's Creative Resources of Intelligence	
Facet of Creativity/Resource	**Description**
Intellectual Abilities	Sternberg identifies three salient abilities: (a) the synthetic ability to see problems in new ways and to escape the bounds of conventional thinking; (b) the analytic ability to recognise which of one's ideas are worth pursuing and which are not; and (c) the practical-contextual ability to know how to persuade others of—to sell other people on—the value of one's ideas.
Knowledge	Argued by Sternberg as both a necessity and potential hindrance to creativity. It is necessary that a person has sufficient knowledge of a given field to move it forward but there is the risk that this knowledge ties the person to certain ways of thinking.
Styles of Thinking	Of importance here is what is termed 'legislative thinking' – a preference to think in new ways as well as an ability to think globally and locally.
Personality	Whilst being understood as fluid attributes that are not fixed, favourable aspects of personality in creative thought include, but are not limited to, willingness to overcome obstacles, willingness to take sensible risks, willingness to tolerate ambiguity, and self-efficacy.
Motivation	It has been shown that creative acts rarely take place unless the person is intrinsically motivated and interested in the field within which they are working.
Environment	This must be supportive and rewarding of creative thinking for failing to do so may result in a person's creativity never being displayed.

Table 2.6

Mihaly Csikszentmihalyi

Csikszentmihalyi (1997), contributes an interaction-based conception of creativity tied closely to 'Flow Theory'. Flow theory identifies a set of conditions which, when met, result in a person's total absorption in what they are doing. During a state of flow, a person's actions and awareness become merged, distraction is excluded, there is no worry of failure, sense of time becomes distorted and activity becomes wholly autotelic. He aligns his understanding of the creative act to the linear staged-model presented by Waller

(1926), however, he argues that creativity arises as a result of a system of interaction consisting of three elements: domain, field and person and that creative acts occur when ‘flow’ is achieved.

Herein, domain is said to consist of its own symbolic elements, rules and system of notation in which a person can think and act and that different domains (e.g. Mathematics and Social Sciences) are structured differently. Field refers to those people who gate-keep the domain and filter those acts undertaken by individuals to determine their worth as new ideas. An idea is essentially creative if it is recognised by the field as being so. Finally, creative people are those who can, using the symbols and properties of the domain, generate new ideas that could change the domain itself or give rise to a new domain. Csikszentmihalyi states there is no single set of characteristics to distinguish creative people from others but describes a range of associated traits and abilities including complex personalities, ability to sustain high levels of concentration and can make use of both convergent and divergent thinking.

2.3.1.3. Creativity in Technology Education

Despite its complexity and challenge, creative thinking is widely recognised as an essential skill for effective design-based problem solving in technology classrooms (see Rutland & Barlex, 2008; Cropley & Cropley, 2010). From the preceding discourse, there is a suggestion that creativity is something that can be nurtured and developed through childhood and that it is possible to engineer an environment that supports and nurtures it. Additionally, there are identifiable thinking skills such as problem finding and analysis that could be developed through design challenges. Both of these are congruent with the assertions of Klein & Shragai (2001), who argue that teachers should provide opportunities for creative behaviour to emerge and involving pupils in real-world problems allows them to better engage their multiple talents and abilities. Lewis (2008), drawing on the work of both Peterson (2002) and Amabile (1998), states that technology classrooms can indeed foster creativity through risk taking, playfulness, freedom and challenge. Wilson & Harris (2004), in reviewing design in UK technology education, found that the opportunity for pupils to design something that did not yet exist helped to develop higher order thinking skills.

The discourse also suggests that truly creative activity as something children would find very difficult, if at all possible, to achieve. Despite a potentially high intellectual demand, there is an accompanying level of immersion, motivation and dynamics of personality and thinking style that pupils may simply not be capable of. Indeed, this is recognised by Feldman, Csikszentmihalyi & Gardner (1994), as 'big creativity' and that which pupils undertake within classrooms is more analogous to 'small creativity' that seeks novelty and new ways of looking at situations.

Recent research within technology education has explored numerous aspects and conceptions of creativity (*see, inter alios*: Lewis, 2009; Bruton, 2010; Kowaltowski et al, 2010; Cropley & Cropley, 2009; Spendlove, 2007). Within this vein of small creativity, Wong & Siu (2011) present a model based on the work of Necka (2003) that accounts for creativity during periods of analysis, synthesis and evaluation as well as accounting for the cyclic nature of such activity (*see* Intellectual Processes section). An additional 3-part model is presented by Rutland & Barlex (2008) based upon the aforementioned work of Csikszentmihalyi. This conceives of classroom creativity as a series of interactions between the person, field-relevant features, process–relevant features and social & environmental features. They argue it should be considered in relation to the following criteria for creativity in the technology classroom:

The Concept or Idea

Has the designer proposed a concept that is original, novel, feasible, useful, will function etc?

Aesthetic Creativity

Has the designer made proposals about those features of the product that will appeal to the senses, for example, sight, hearing, touch, taste and smell? Is there something about these proposals that is particularly novel and attractive?

Technical Creativity

Has the designer made proposals about the way the product will work and the nature of the components and materials required to achieve this? Is there something about these proposals that is novel or elegant?

Constructional Creativity

Has the designer made proposals about the way the product will be constructed and the tools and processes needed to achieve this? Is there something about these proposals that is novel or original?

Though these models conceptually align creativity with the classroom, other studies provide evidence of factors that may mitigate pupil creativity in practice. One of the most salient and significant is that of 'Cognitive Fixation', described by McLellan & Nicholl (2011). Cognitive fixation is a form of normative thinking, in which pupils adopt the path of least resistance and converge on knowledge that is most immediately accessible to them. This is often cultural knowledge which results in designs taking on the form of things such as love hearts, footballs, initials or that which the teacher has just demonstrated. Reasons for this are said to include the way in which learning is presented and a lack of risk taking on the part of the pupil. Figures 2.4 and 2.5 show pupil artefacts before and after development work undertaken by this author to remove the effects of cognitive fixation in an S2 (Secondary School, Year 2) design and make project.

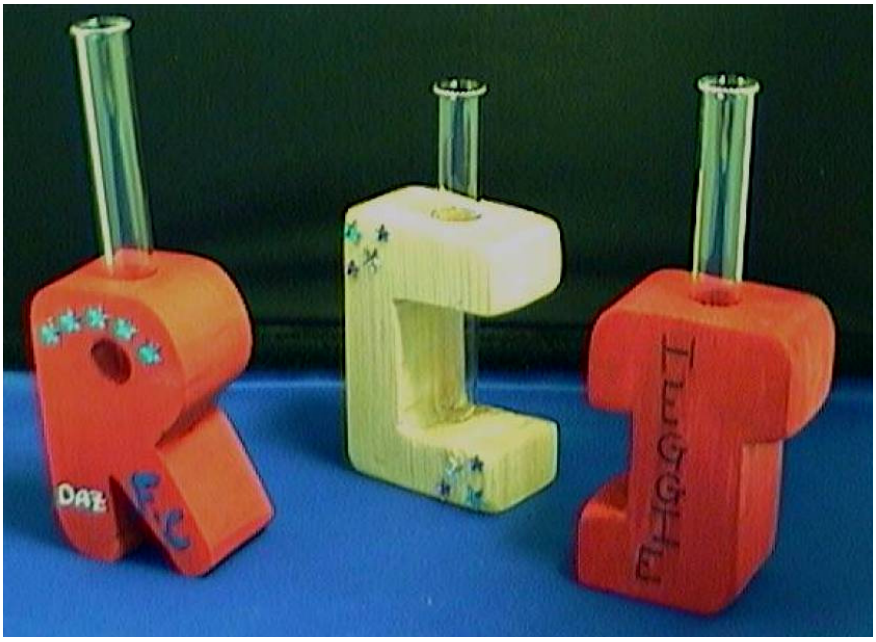


Figure 2.4 – Pupil Work Prior to Reduction of Cognitive Fixation

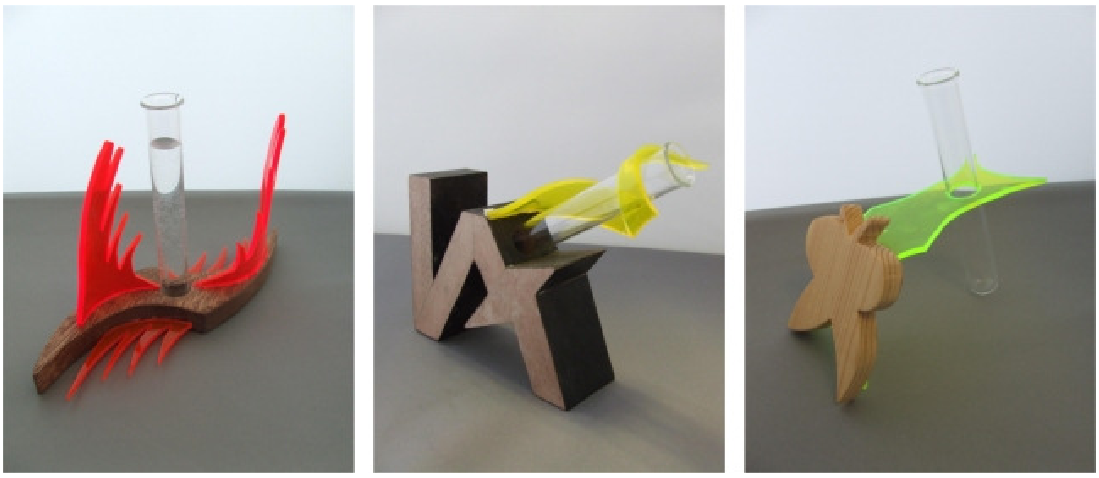


Figure 2.5 - Pupil Work Following Reduction of Cognitive Fixation

2.3.1.4. Expert & Novice Paradigms in Design Research

Research into design-based problem solving also contains discourse concerning the differences between 'novice' and 'expert' designers. A study by Hill & Anning (2001), investigating the differences between how design is taught and how it is exercised in the workplace draws the following conclusions:

1. Novice designers design differently across and between age groups.
2. They found that expert designers worked very much as part of team whilst novice designers had no opportunity for this.
3. They also recognised the roles of novice designers' interests in, attitudes towards and perceptions of technology within design and that this varied between sexes.

These findings are also touched on by research carried out by Davies (1996b), in which some key features of professional designers' practise are highlighted as suitable for use in the classroom. These include: (a) discussion at all stages of the design process, (b) continual reference back to the project aims, (c) on-going evaluation, and (d) sketches and 'visual thinking'. These features identified by Davies appear sensitive to the differences between classroom-based and professional design, however, it could be argued that studies of this nature should exercise similar caution with respect to notions of 'transplanting' professional design practise into the work of pupils who are still developing the necessary thinking skills. In terms of more global characteristics such as structure and learning context, Anning (1996), draws on the considerations of Medway (1992) and an unpublished letter from David Barlex[2], that contend many of the design activities individual pupils carry out in the classroom would actually be carried out by large teams of experts in areas such as model making, marketing and production. This raises the question posed by Lewis (1999), who, in discussing the structure of technology asks: "does school technology have to be a mirror image of the discipline of technology?" (p.6). Lewis draws upon the observations of Stengel (1997), who claims that school subjects can precede academic disciplines in that they are not externally controlled by experts, but also highlights the risk that the needs of children may be overlooked. Further to this, those working within a professional design environment have already undergone the education and skills development about which pupils are still learning and developing.

---

[2] David Barlex is a prominent researcher within the field of Technology Education.

This section expanded and analysed 'Design' as one mode of technological problem solving defined by McCade (1990). The following section explores 'Troubleshooting' as the second mode he proposes.

2.3.2. Troubleshooting as Technological Problem Solving

Troubleshooting constitutes the second category of technological problem solving provided by McCade (1990). As discussed by MacPherson (1998), troubleshooting can be considered a subset of technological problem solving in as far as it comprises both shared and unique characteristics such as given and goal states. In his categorisation, McCade (1990), claims that troubleshooting is concerned with identifying and overcoming problems encountered during the production or use of a technical solution. Firstly, in regard to the production of technical solutions, troubleshooting can be conceptualised as a method of solving emerging problems (*see* McCormick, 1996), and the subsequent problem solving processes exist within, and are determined by, the context that is the larger, global problem. In a pilot study of children's problem solving processes in technology, McCormick (1994), discusses what he terms 'emergent problems' arising within the process of students designing and constructing a kite. McCormick observed that these individual challenges faced by the pupils were largely as a result of their detraction from a prescribed, linear problem solving process (p.10). This being said, it could also be argued that problems emerge during one stage, such as manufacture, because they were largely unforeseen at a previous conceptual stage.

Despite there being shared characteristics with other types of technological problem solving, there are also distinct differences. McCade (1990), also argues that troubleshooting is the "systematic approach to locating and correcting problems in existing systems." Interestingly, this characterises troubleshooting as very different from design. While there are arguments surrounding the inappropriate over-systematising of design, troubleshooting is seen, by contrast, as highly systematic and more structured by nature. Specifically, McCade (ibid), asserts that troubleshooting is the product of three features: knowledge of the inter-relationship of systems and sub-systems; knowledge of the function and operation of sub-systems, and finally, a search strategy. This framework suggests that the success, or otherwise, of troubleshooting efforts is largely determined by the level of the solvers knowledge of the artefact or system under scrutiny. The notion of a search 'strategy' suggests an approach, not only informed by symptoms and knowledge of the system, but also devised prior to action being taken. Moreover, whilst both design and troubleshooting are exploratory by nature, in many senses, they represent divergent and convergent approaches to problem solving. The former is more likely to afford greater creativity and novelty, as it is not necessarily tied so tightly to the 'rules' of the system. If creative thinking were employed in the latter, it would more likely be recognised as innovation or 'technical creativity'.

Indeed, the systematic and structured nature of troubleshooting is exemplified through many of the 'models' used within industry and the commercial world, and there is evidence that highly structured troubleshooting can yield more success than less structured troubleshooting (Schaafstal et al, 2000). Here, troubleshooting is very much conceived of as a process that can, to a large degree, be applied independent of the problem situation and is, hence, not context specific.

2.3.2.1. Troubleshooting in Technology Classrooms

The idea that there is more than one form of troubleshooting can be explored by comparing 'Troubleshooting', as defined by McCade (1990), and 'Emergent Problem Solving' as discussed by McCormick (2000). Here, it can be argued that their differing forms arise from the contexts within which they occur. Technological problems may take a variety of forms and, by inference, it can be assumed that the problems that arise through seeking a suitable solution are just as varied. Despite McCade (1990), making explicit reference within his definition to 'troubleshooting during the production of technical solutions', the framework he presents in support of this, is far more conducive to a highly structured troubleshooting process, applicable to an already complete technological solution or artefact. This is similar to the type of problem solving pupils might undertake in Higher Technological Studies (*see* SQA, 2011), when required to ascertain why the electronic circuit they have just built does not work, and resolve the problem. Here, the nature of the intellectual domain is very structured, governed by laws, conceivable in terms of systems, and well suited to more structured problem solving. If undertaking more open-ended, design-based problem solving, technical solutions are still being developed, although not necessarily in as structured a fashion. If we cite the example provided by McCormick et al (1994), of emerging problems during the production of kite (the technical solution), it is conceptually very difficult, and arguably unnecessary, to meaningfully represent a kite using the systems approach, aside from conceptualising components of force in equilibrium, which may or may not even be conducive to resolving the problem. Moreover, the framework also implicitly assumes the designer has mastery of knowledge associated with the solution that is, in fact, still likely to be evolving and partly unknown. In summation, this suggests that, although pupils will solve problems that arise during the production of a technical solution, the term ‘troubleshooting’, as conceived here, may be not always be appropriate.

In light of this, and the discourse by McCormick (1996) surrounding emerging problems, it is accepted that ‘Emergent Troubleshooting’ constitutes a second form of troubleshooting. Although this is not as structured or as precisely defined as troubleshooting, within the context of a larger problem solving process, it can be considered to be similarly reactive in nature. In all of the aforementioned models and definitions, troubleshooting involves both locating a problem and taking the necessary action to rectify or reduce that problem and emergent troubleshooting also satisfies these conditions; albeit within the context of more open-ended problem solving.

In accordance with these considerations, this thesis defines two separate forms of troubleshooting. The first is termed ‘Discrete Troubleshooting’ in accordance with the definitions developed by McCade (2000). The second is termed ‘Emergent Troubleshooting’ to account for the differing contexts in which arising problems might be solved. Table 2.7 describes these in terms of context, applicability and structure.

Troubleshooting as Reactive Technological Problem Solving			
	Context	Most applicable to:	Degree of Structure:
Discrete Troubleshooting	Discrete and complete problem solving process.	Existing technological solutions that can be conceptualised through the systems approach.	Can be very highly structured and systematic although solutions could be ‘innovative’ in the context of the system and faults.
Emergent Troubleshooting	Occurs within a larger problem solving process.	Developing technical solutions that are not easily conceptualised using the systems approach.	Is often not as highly structured and has greater scope for insight and creativity.

Table 2.7

This section explored dimensions of troubleshooting; the second mode of technological problem solving defined by McCade (1990). In doing so, two forms of troubleshooting were identified: ‘discrete’ and ‘emergent’ reflecting the possible contexts and structures within classroom activity. The following section critically analyses ‘Impact Evaluation’ as his final proposed mode.

2.3.3. Impact Evaluation as Technological Problem Solving

Impact evaluation is considered as the third and final mode of technological problem solving. McCade (2000), defines impact evaluation, or technology assessment, as a type of technological problem solving necessary to distinguish between 'technicians' and 'technologists'. He argues that it consists of the critical analysis of design solutions such that possible outcomes may be predicted and the most suitable solutions selected. Furthermore, he argues that if this is done within a well-structured framework it constitutes problem solving, manifest in the logical conjoining of discrete pieces of information to produce a coherently justified essay. The extent, however, to which this can be legitimately defined as a form of technological problem, is limited.

Though it is possible to define the construction of a critically analytical essay as a form of problem solving, a central and fundamental consideration is overlooked when defining this as technological problem solving. The results arrived at by this problem solving process are exclusively conceptually manifest. Whilst this does not necessarily deny that it may have elements that can be conceptualised as part of technological thinking, it does deny that it can ever produce a 'solution' to a technological problem. In considering the topic offered by McCade (1990): 'Technological Impacts of Transport Systems', pupils applying a well-structured critically analytical process will, at best, produce a recommendation as the identified negative impacts of the transport system will still exist as they did prior to the pupil applying this process. This does not compliment the defining assertion, upheld in this thesis, that technological problem solving must yield a physical solution to the problem (Custer, 1995; Herschbach, 1995).

2.3.4. The Systems Approach as Technological Problem Solving

Depending upon the nature of the technological content being looked at, the systems approach allows ideas and processes to be conceptualised in terms of their inputs, processes, outputs and the functional relationships that interconnect them. The systems approach is often employed with the areas of electronics and control systems and is highly analytical in nature allowing existing systems to be broken down as well as new ones to be conceived. An example of the systems approach being used to analyse part of a computer mouse in Higher Technological Studies is shown in Figure 2.6.

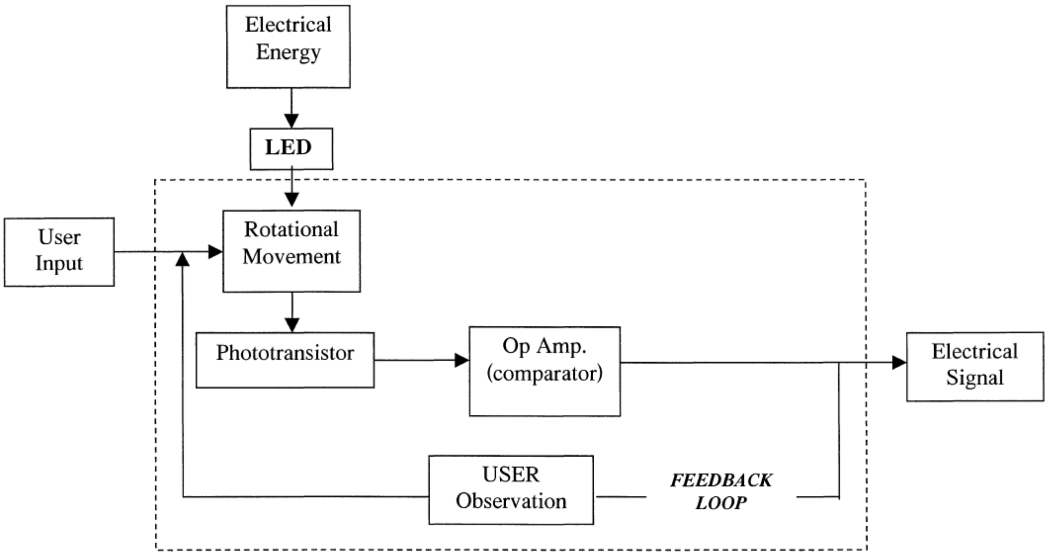


Figure 2.6 - Systems Approach Analysis of a Computer Mouse

Jones (1994), in exploring technological problems in science classrooms discusses pupils' use of the systems approach in designing such things as a door bell for the deaf. Whilst the focus of his research is the pathways through technological problems and technological capability, it is clear that the systems approach can be seen as a method employed within a larger problem solving, or design, process. As with any method, its use and application can be more or less effective, however, it is best suited to problems within more defined intellectual domains where relationships between concepts can be clearly identified. It subsequently stands to reason that problem solving is less open to aspects such as aesthetic creativity but may yield elements of innovative thought.

Of significance here, is the fact that the systems approach constitutes one method that could be employed to solve problems that are previously considered by Twyford & Järvinen (2000) as 'prescribed', insofar as the outcome is often known in the brief. Although solving this type of problem in technology education is far less researched than more open, design-based approaches, it is arguably of no lesser importance and, in some senses, is closer to the types of problem solving found in more industrial and commercial environments.

2.3.5. Identified Modes of Technological Problem Solving

In the preceding discourse, four modes of technological problem solving are identified. Whilst numerous philosophical considerations and assertions have been discussed, the central definitional distinction argued in this thesis is that, for technological problem solving to be recognised as distinct from general, or other domain specific conceptions of problem solving, the solution or outcome of the problem solving process must be manifest in a physical form.

For the purposes of this thesis, the four identified modes and descriptions of technological problem solving are presented as follows:

Mode 1: Ill-Defined Technological Problem Solving (Proactive)

Seeking practical solutions to ill-defined problems, needs or aspirations.

Normally address through design. Argued as the central problem solving mode within technology education, design draws on creative thinking to arrive at original solutions that are manifest in physical form. It may or may not begin with a problem and, although often conceived as identifiable linear stages, is often iterative in reality and the outcome is unknown, to some degree, in the brief. This form of technological problem solving is likely to give rise to a range of possible solutions.

Mode 2: Well-Defined Technological Problem Solving (Proactive)

Seeking practical solutions to problems about which more is prescribed at the onset.

Could be addressed using a variety of approaches including the systems approach, and aspects of either the given state, goal state or both are known. Whilst this does not employ creativity to the degree observed within open-ended problem solving, there is still scope for novel and innovative approaches. This approach is arguably reflective of the types of problems undertaken by engineers who often have to make improvements within the parameters of the given materials and systems. If appropriate, it may still be generally approached in a similar fashion to ill-defined, design type problem solving.

Mode 3: Emergent Trouble Shooting (Reactive)

Less structured solving of smaller problems that arise during the course of seeking a practical solution to a larger problem.

This type of problem solving would likely be observed during the phase where pupils turn their conceptual ideas into physical solutions and may be more or less structured in nature.

Mode 4: Discrete Trouble Shooting (Reactive)

Highly structured and systematic solving of problems that arise with a technological artefact.

This would often be observed as a stand-alone process in areas such as electronics and control. It is unlikely that pupils would be in the situation where they would be expected to discretely troubleshoot and repair products or solutions that they have not developed. It is also likely that where it does occur, it would be with guidance from the teacher.

2.4. Section 4 – The Intellectual Processes of Technological Problem Solving.

Section 3 explores and establishes four modes of technological problem solving. 'Modes' constitute the first of the three strands of the definition of technological problem solving developed in this thesis. This section explores 'Intellectual Processes' as the second of the three strands and identifies a broad range of possible processes that pupils may draw upon in the process of solving a technological problem.

As described in the last chapter, there was a notable shift from the behaviourist rejection of the internal mechanisms of problem solving to the cognitive embracing thereof. Building upon the aforementioned 'Test-Operate-Test-Exit' model (Miller, 1960), various fields have defined a range of underlying mental processes, though the work of Benjamin Bloom was possibly more influential in fuelling this shift. Its prominence in educational settings today is testament to this. Figure 2.7 illustrates the Taxonomy of the Cognitive Domain (Bloom, 1956), which established a range of mental processes ordered in terms of complexity and difficulty.

Evaluation
Synthesis
Analysis
Application
Comprehension
Knowledge

Figure 2.7 – Bloom's Taxonomy of the Cognitive Domain

Bloom, through analysing a range of answers to examination questions, ascertained these processes and ordering on the basis that more correct answers were given to application questions than were to analysis questions, and so forth. It was originally designed as a means of standardising communication about examination questions but has since, in the opinion of this author, been applied to a vast range of learning situations, often erroneously. There are three areas in which some critical limitations and concerns lie regarding this taxonomy in general learning contexts:

1. Despite Bloom stating that no level of the taxonomy should be seen as more valuable than any other, there is a tendency for knowledge to be seen a subordinate to process, though it has been shown that knowledge is implicit in all of the above levels (Bereiter & Scardimallia, 2005).

2. The taxonomy is ordered by 'difficulty', which is arguably a relative and fluid concept and this is argued as highly problematic (Marzano, 2006). What is initially difficult tends to become less so with practice. Indeed, current thinking suggests the perceived difficulty of a process depends on the depth to which people must engage with it; it may be easier to briefly evaluate why you prefer one painting over another than it is to recount the somewhat abstract sin, cos and tan rules; both may be easier than comprehending string theory. With this in mind, Bloom states that the taxonomy is only true for learning material seen by students for the first time.

3. The separation of processes into five levels suggests a high degree of mutual exclusion, which has since been contested. As reflected by more recent understanding, and as argued by Moore (1982), evaluative processes occur constantly in learning and throughout every level of the taxonomy. Similar assertions could be made about analytical processes and any of the levels below.

The significance of the processes identified within Bloom's work cannot be underestimated, although the arrangement within a taxonomy does not reflect the complexities of learning and problem solving situations relevant to this study.

Johnson (1997), presents an example of a more recent and non-hierarchical model of core thinking skills developed by Marzano et al (1988). Shown below in Figure 2.8, this provides a general overview of the areas and types of cognitive process.

Focusing Skills
1. Defining problems
2. Setting goals

Information Gathering Skills
3. Observing
4. Formulating questions

Remembering Skills
5. Encoding
6. Recalling

Organizing Skills
7. Comparing
8. Classifying
9. Ordering
10. Representing

Analyzing Skills
11. Identifying attributes and components
12. Identifying relationships and patterns
13. Identifying main ideas
14. Identifying errors

Generating Skills
15. Inferring
16. Predicting
17. Elaborating

Integrating Skills
18. Summarizing
19. Restructuring

Evaluating Skills
20. Establishing criteria
21. Verifying

Figure 2.8 – Non-Hierarchical Model of Core Thinking Skills

Many of these can be seen to relate directly to problem solving within technology. However, much of what forms the basis for this categorisation stemmed from the general research into expert and novice thinking discussed earlier in this chapter.

This idea of examining the modus operandi of the expert and novice has also allowed for conclusions to be drawn more specifically within realm of technological problem solving. In his inquiry of 'real-life', industrial, problem solving, MacPherson (1998), examined troubleshooting by technicians and concluded that experience, technical knowledge and critical thinking, rather than cognitive or problem solving styles, were accurate indicators of problem solving ability. Welch et al (2000), noted that whilst expert designers make significant use of sketching, novice designers opt out of sketching entirely in favour of 3D Modelling most likely due to a lack of skills and experience, though some studies show this changes with age (e.g. Gustafson & Rowell, 1998). Hill & Anning (1996), explicitly compare the way professional design thinking takes place and the way classroom-based design thinking takes place. They drew many conclusions which included the fact that workplace designers work as part of team, school-based design often makes extensive use of drawing skills, modelling skills and design process skills, and that there were actually significant variations in approach within, and between, both groups. However, an examination of the work of expert technologists such as Thomas Edison and Frank Lloyd Wright, carried out by Halfin (1973), lead to a significant contribution in terms of process identification. Through use of the Delphi Technique, Halfin was able to compile a list of 17 mental processes associated with technological thinking (shown in Table 2.8, Parts 1&2). These processes have been validated by Hill & Wicklein (1999) and successfully employed in the exploration of pupils' technological thinking by Hill (1997), and Kelley & Hill (2007), amongst others. It is clearly necessary to allow for a lower level of mastery and complexity in the use of such processes by novice designers.

Halfin's Intellectual Processes of Technology (Part 1)	
Mental Process	**Description**
Defining the problem or opportunity operationally	The process of stating or defining a problem that will enhance investigation leading to an optimal solution. It is transforming one state of affairs into another desired state.
Observing	The process of interacting with the environment through one or more of the senses (seeing, hearing, touching, smelling and tasting). The senses are used to determine the characteristics of a phenomenon, problem, opportunity, element, object, event, system or point of view. The observer's experiences, values and associations may influence the results.
Analysing	The process of identifying, isolating, taking apart, breaking down or performing similar actions for the purpose of setting forth or clarifying the basic components of a phenomenon, problem, opportunity, object, system or point of view.
Visualising	The process of perceiving a phenomenon, problem, opportunity, element, object, event or system in the form of a mental image based on the experience of the perceiver. It involves an exercise of all the senses in producing a valid mental analogy of the phenomena involved in a problem or opportunity.
Computing	The process of selecting and applying mathematical symbols to describe, estimate, calculate, quantify, relate and/or evaluate in the real or numerical sense.
Communicating	The process of conveying information (or ideas) from one source (sender) to another source (receiver) through a media using various modes (oral, written, picture, symbol or any combination thereof.)
Measuring	The process of describing characteristics (by the use of numbers) of a phenomenon, opportunity, element, object, event, system or point of view in terms which are transferable. Measurements are made by direct or indirect means, are on relative or absolute scales, and are continuous or discontinuous.

Table 2.8 (Part 1)

Halfin's Intellectual Processes of Technology (Part 2)	
Mental Process	**Description**
Predicting	The process of prophesying or telling something in advance, predicting the future based on special knowledge.
Questioning and Hypothesising	Questioning is the process of asking, interrogating, challenging or seeking answers related to a phenomenon, problem, opportunity, element, object, event, system or point of view. Hypothesising is the process of stating a theory of relationship between two or more variables to be tested which are aspects of a phenomenon, problem, opportunity, element, object, event, system or point of view.
Interpreting Data	The process of clarifying, evaluating, explaining and translating to provide (or communicate) the meaning of particular data.
Constructing Models and Prototypes	The process of forming, making, building, fabricating, creating or combining parts to produce a scale model or prototype.
Experimenting	The process of determining the effects of something previously untried in order to test the validity of a hypothesis, demonstrate a known (or unknown) truth or try out various factors relating to a phenomenon, problem, opportunity, element, object, event, system or point of view.
Testing	The process of determining the workability of a model, component, system, product or point of view in a real or simulated environment to obtain information for clarifying or modifying design specifications.
Designing	The process of conceiving, creating, inventing, contriving, sketching or planning by which some practical end may be effected, or proposing a goal to meet the societal needs, desires, problems or opportunities to do things better. Design is a cyclic or iterative process of continuous refinement and improvement.
Modelling	The process of producing or reducing an act, art or condition to a generalised construct that may be presented graphically in the form of a sketch, diagram or equation; presented physically in the form of a scale model or prototype; or described in the form of a written generalisation.
Creating	The process of combining the basic components or ideas of phenomena, objects, events, systems or points of view in a unique manner which will better satisfy a need either for the individual or for the outside world.
Managing	The process of planning, organising, directing, co-ordinating, and controlling the inputs and outputs of the system.

Table 2.8 (Part 2)

It is recognised that these key intellectual processes share a degree of overlap with that which other researchers have identified. Williams (2000), for example, identifies Evaluation, Communication, Modelling, Generating Ideas, Research and Investigation, Producing and Documenting as central technological thinking skills. DeLuca (1992), identifies trouble shooting/debugging, scientific process, design process, research and development and project management to be of central import. Paradoxically, considering the conclusions of Marzano et al (1988), Halfin (1973), Williams (2000) and DeLuca (1992) within the context of this study, serves to both validate and promote tension in defining intellectual processes. This tension arises from the differences between the structures and definitions of the processes cited. For example, Halfin (1973) defines both design and analysing as mental processes. When designing, however, it is likely that a pupil will undertake some form of analytical thinking as suggested by Marzano et al (1998), albeit on a smaller scale. Both Marzano (1988) and Williams (2000) identify the process of Evaluation, but Halfin (1973) does not; rather, it is implicit with a broad range of other processes (as argued by Moore, 1992 – see above). Whilst evaluation could be accounted for through a combination of processes such as questioning and testing, the nature of evaluation in a task may differ greatly from less formal, micro-level, evaluations made during the construction, to a larger formal evaluation at the end.

Further to these considerations, there arises the notion of 'discrete' and 'on-going' processes. From those identified, processes such as observation, visualising, encoding, recalling and managing are likely to, in a sense, permeate technological problem solving activity. This is also true of the 'encoding' process highlighted by Marzano et al (1988), a critical underlying mechanism in the creation of mental representations and the construction of knowledge during problem solving (*see* Jonassen, 2000; Stevenson, 2004). Processes such as computing, measuring, documenting, testing, and forward planning (*see* Hennessey & Murphy, 1999; Baker-Sennett et al, 1993) although they may be undertaken regularly throughout the duration, are likely to be more discrete in their manifestation.

2.4.1. The Application of Intellectual Processes

Three separate studies carried out by Argyle (1967), Mioduser & Kipperman (2002), and Scrivener et al (2002), strongly suggest that pupils move through technological or design-based problem solving in an iterative or cyclic fashion. These respective studies present three models, shown in Figures 2.9, 2.10 and 2.11, that, although differ in complexity, illustrate a similar underlying cyclic/iterative mechanism, not unlike that proposed by Miller (1960).

The 'Motor Skill Process Model' (Figure 2.9), developed by Argyle (1967), is a general model describing progression through practical activity and the resultant development of practical skill, both explicit and tacit. The translation phase is the one in which intellectual processes are employed and the feedback through perception forms the cyclic action common to subsequent models.

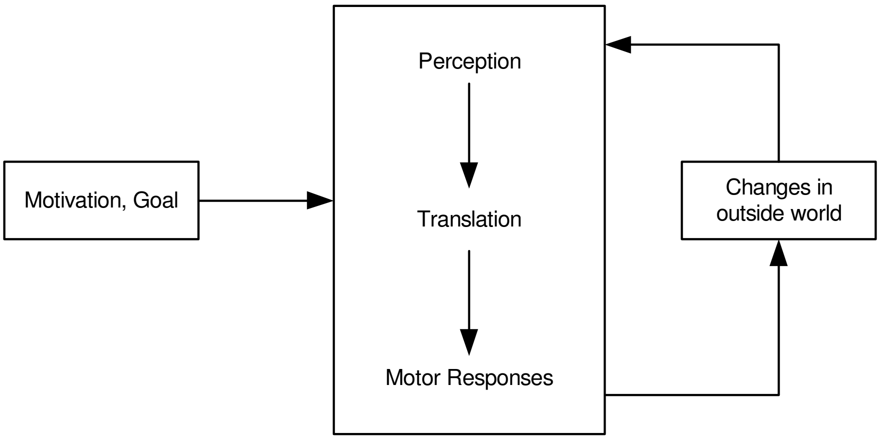


Figure 2.9 – Motor Skill Process Model (Argyle, 1967)

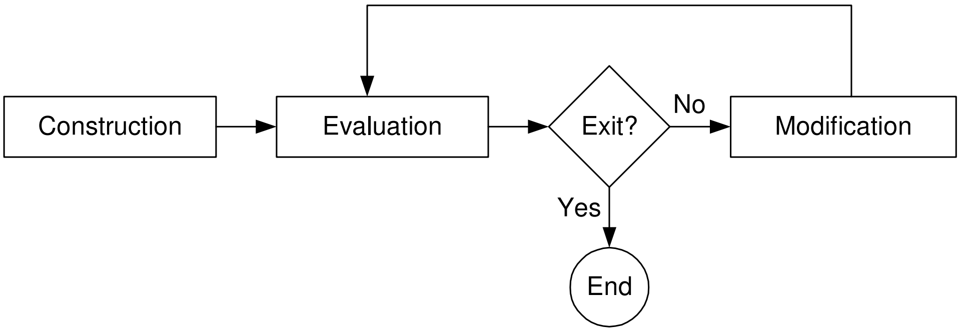


Figure 2.10 - Evaluation-Modification Loop in the Practical Milieu
(Mioduser & Kipperman, 2002)

Figure 2.10, specifically developed within the realm of school-base technological problem solving, shares much in common with, and expands, the 'Motor Skill Process Model' (Figure 2.9). Within the Evaluation Phase, pupils tested their solutions functionality and were shown to abandon their goal, reduce their goal, stick to their goal or improve their goal. In the resulting modification phase, they were shown to construct something new, troubleshoot, repair, change or experiment.

The model in Figure 2.11 has its basis in the work of Groot (1969), Kim (1990) and Roozenberg & Eekels (1995) and extends the three core processes of 'analysing', 'ideating' and 'evaluating' identified therein, to include both requirements (referred to within the model as REQs) and outcomes for each. It also suggests that the creation of ideas and the evaluation of the resultant proposal are carried out in relation to a set of requirements, which may well change as the solution progresses. Common, again, to this model is the cyclic mechanism underlying the application of processes.

From the above discussion, it is clear that technological problem solving draws on a vast range of intellectual processes, many of which place significant cognitive demand on the pupil; something echoed by Waetjen (1989), who describes technological problem solving as a key tenet of higher order thinking.

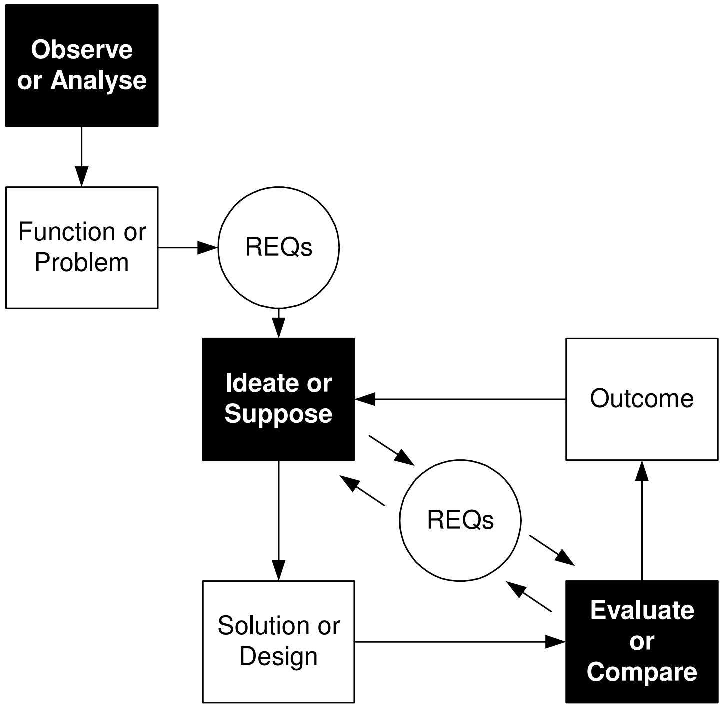


Figure 2.11 - An Extended Design Problem-Solving Process Model (Scrivener et al, 2002)

2.5. Section 5 – The Epistemology of Technological Problem Solving

Sections 3 and 4 explore 'Modes' and 'Intellectual Processes' as the first and second strands of technological problem solving. This section explores 'Epistemology' as the third and final strand identifying conceptual knowledge, procedural knowledge, tacit knowledge and knowledge of principles and relationships as core to technological activity.

Defining what constitutes 'technological knowledge' has been the focus of much research over the past few years (Custer, 1995, McCormick, 1999, Vincenti, 1990). Within technology education, the motivation behind this movement has largely been the perceived need to define a framework that establishes technology as a discipline with its own set of concepts and knowledge. It is not the intention of this thesis to develop these epistemological arguments for technology as a discipline, but rather to examine them within the context of the developing definition of technological problem solving. It should be acknowledged that the considerations made within the following discussion, whilst perhaps possessing areas of commonality, are not intended to be readily applicable to other philosophical conceptions of technology.

In view of technology education as a whole, Hennessey & McCormick (1994), conclude that knowledge within technology can be split into 'procedural' and 'conceptual' knowledge; where 'procedural' relates to activity within technology and 'conceptual' relates to the body of content (see also: Kimbell, 1991). This, in broad terms, parallels 'declarative' and 'procedural knowledge' defined by Anderson (1983) as 'knowing that' and 'knowing how' respectively. According to the definitions of Hennessey & McCormick (1994), as a process, technological problem solving can be broadly categorised within the realm of procedural knowledge. However, this should not infer that it is either mutually exclusive from conceptual knowledge, or that these comprise the only categories of knowledge relevant to technological problem solving. Lewis (1999), critically examines these categories in relation to technology education and argues that they should be viewed symbiotically rather than as discrete factions. This leads to the idea that new conceptual knowledge may be borne from applied procedural knowledge and that applied existing conceptual knowledge may generate new, or refine existing, procedural knowledge. Consequently, this is recognised as very complex and nebulous inter-relationship.

In technological education research, a great deal of work has been undertaken to examine the roles of different types of knowledge and the acquisition thereof (e.g. Senesi, 1998; Erkip et al, 1997; Anning et al, 1996). From much of this, it can be seen that conceptual and procedural knowledge, whilst serving as a robust distinction, are not the only necessary epistemological considerations. This thesis hence explores the epistemology through five themes, before integrating the resultant assertions with the previous two stands of 'Mode' and 'Intellectual Process' in an original conceptual model of technological problem solving.

The exploratory theses for the epistemology strand of technological problem solving are:

1. Technology as Applied Science
2. Knowledge of Principles & Relationships
3. Technological Knowledge as a Function of Practice
4. Conceptual Knowledge and Knowledge of Principles
5. Procedural Knowledge and Knowledge of Principles

2.5.1. Technology as Applied Science

The first argument in support of this can be derived from the discourse surrounding the relationships between science and technology. De Vries (1996), discusses the thesis posited by Bunge (1966), that technology can be conceived of as "applied science" and points out that this became an accepted but misrepresentative paradigm for many years. Custer (1995), bolsters this by drawing attention to the naïve fluidity and lack of distinction between science and technology within the popular press, and even some academic circles (p.226); which unfortunately continues today. In spite of this lay assumption, a growing body of contemporary research and thinking challenges the applied science paradigm insofar as it presupposes technology is without its own body of knowledge. Importantly, retrospective studies have indicated that in many instances, scientific knowledge, defined by Herschbach (1999), as: "an expression of the natural world and its phenomena", often plays only a limited role, if any, in the design and development of technological artefacts (*see* de Vries, 1994; Vincenti, 1990). This is reflected in the more contemporary assertion that scientific knowledge, and the application thereof, constitutes one, but not the only component of technology. Vincenti (1990), cites a statement written to the Royal Aeronautical Society by a British engineer in 1922:

> *"Aeroplanes are not designed by science, but by art in spite of some pretence and humbug to the contrary. I do not mean to suggest for one moment that engineering can do without science, on the contrary, it stands on scientific foundations, but there is a big gap between scientific research and engineering product which has to be bridged by the art of the engineer." (p.4)*

This statement augments the notion that although 'technology' may apply 'science', it is not the same as, nor consists entirely of, applied science. Additionally, the term 'science' is arguably pseudo-synonymous with 'scientific knowledge' and that this, in turn, covers a vast range of areas from quantum string theory through to ornithology; not all of which will be readily applicable to technological solutions. Moreover, this variance is reflected in the resultant lack of consensus, within research literature, as to the very definition of scientific knowledge (*see* Meichtry, 1999).

As well as the contention with the assertion underlying the phrase 'applied science', and the shear scope of scientific knowledge, there is also evidence questioning the appropriateness of the term 'applied' in instances where such knowledge is indeed drawn upon. Echoing the sentiment of the British Engineer, Ropohl (1997), suggests the notion that scientific knowledge is simply 'applied' in these instances is an oversimplification. To this end, he shows, through the use of Hooke's Law in designing a technical solution, that the process is better described as one of transformation, rather than mere application, insofar as the engineer actually develops an equivalent 'technological law' from Hooke's Law, and applies this instead. Furthermore, it is the identification of 'technological laws', which questions the appropriateness of the over-arching phrase 'scientific knowledge' within this thesis.

2.5.2. Knowledge of Principles & Relationships

To facilitate the intended exploration of technological problem solving within classrooms, 'scientific knowledge' is necessarily considered to be only those known principles, concepts, laws and relationships of the natural world most readily applicable to classroom-based technological activity. Examples of such scientific knowledge include, but are not limited to, melting points, turning moments, ohm's law, equilibrium, potential energy or demonstrating a relationship between two or more variables. Ropohl (1997), in his exploration of technical knowledge, demonstrates the existence similar forms of knowledge within the 'intellectual domain' of technology. Just as with scientific laws, these constitute a relationship between variables or concepts, but arise from the transfomative shift from theory to practise when producing a physical solution. The argument in the example of Hooke's Law is that the engineer is not interested in the scientific explanation thereof, but rather the point at which the law fails to apply, as this is indicative of when the component will fail. The tolerance about this failure stress is tested empirically and, through this process, the engineer derives a technological law that states:

> *"Whenever the maximum tension effected on a component does not exceed the established percentage of the marginal tension at which Hooke's Law ceases to be valid, the component will be wear-resistant."*

Ropohl argues it is this technological law that the engineer will apply and not the related scientific one. He further asserts that, in many instances, technological laws, such as those of metal cutting, are derived entirely from empirical activity and have no coherent scientific basis. Furthermore, because technology does not seek scientific truth, but rather practical success, this is sufficient. Henceforth, this thesis will utilise the term 'Knowledge of Principles and Relationships' instead of scientific knowledge in recognition that these may have a basis aside from scientific. This is also prudent in the sense that technological problem solving may draw upon principles from disciplines such as psychology and economics as necessary for the development of a successful solution.

2.5.3. Technological Knowledge as a Function of Practice

Central to this theme is the observation from Hindle (1966), that technology seeks ways of making and doing things expressed in terms of three-dimensional objects. This, and the aforementioned assertions, strongly suggests there is a discrete body of technological knowledge associated in the shift from concept or natural law to technical artefact. Custer (1995) defines such knowledge as “a function of practice or activity.” He demonstrates that this knowledge can be seen manifest in such things as the inventions of the industrial revolution, citing instrument and telescope making as examples of ingenuity and creativity quite apart from the application of scientific principles and knowledge (p.226). Sharing similarity with the conceptual/procedural distinction, Custer (1995) states technological knowledge can be conceived of as knowledge about “doing things” and “the way things work” (p.227); characteristic of the knowledge used by car mechanics or plumbers, for example. Herschbach (1999), supports this idea through stressing the essential characteristic of ‘technological knowledge’ is that it arises from and is embedded within human activity makes the praxiological distinction between the ‘knowing’ of science, and ‘doing’ of technology’.

McCormick (1999), comments on technological knowledge and argues that it is often highly context dependent and serves to reduce the level of abstraction within a given task; something that is, by contrast, often desired within the scientific realm. Through the example of calculating collisions between pool balls within physics, it is noted that assumptions such as no friction between the snooker balls and the cloth are necessarily made to reduce the complexity of the calculation. McCormick argues that, whilst the mathematical complexity increases exponentially after two collisions, the ‘practical knowledge’ of a pool player allows them to predict as many as four or five shots in advance. Of significance here, is that this knowledge as a function of practice, is developed without the conscious application of refined scientific proofs and principles. This example relates not only to the procedural, more than conceptual, aspect of knowledge, but also suggests a necessary level of skill and judgement which bears notable resemblance to the considerations made by Vincenti (1990) through his analytical study of engineering knowledge.

Herein, Vincenti (1990) identifies three types of knowledge: descriptive, prescriptive and tacit. These are located within the spheres of 'explicit' and 'implicit' knowledge; the former relating to knowledge that can be accounted for overtly in words, tables, diagrams and pictures, and the latter relating to an individual's skill and judgement, as in the example cited by McCormick (1999). Vincenti (1990) recognises descriptive knowledge as explicit knowledge of things as they currently are, whilst 'Prescriptive knowledge' is explicit knowledge about what has to be done in order meet the desired state. By contrast, 'tacit knowledge' is implicit within activity resulting mainly from an individual's judgement, skill and practice (see also Welch, 1998; Schön, 1983 and Polanyi, 1967). This is largely synonymous with 'tacit knowledge', defined by Sternberg et al (2000), as having three characteristics: (a) it is developed with little or no environmental support, (b) it is procedural[3], and (c) it is knowledge that is practically useful (p.107). Whilst all of these factors are integral, the permeating notion that it developed with an individual's practice is critical. As discussed by Morgan (2008), procedural knowledge, which is initially explicit, shifts over time to become implicit when an individual masters the process in question. A common example of this can be found in learning to drive car. Initially, there is a high demand on concentration and judgment for the novice driver to perform quite routine manoeuvres, but through experience, these processes become almost sub-conscious. This is especially significant for technological problem solving where the success of moving from concept to physical solution demands a level of practical skill and judgment from the pupil (see Losse et al, 1991).

The related distinctions offered by Custer, McCormick, Sternberg and Vincenti, and associated reasoning, strongly suggest that the cognitive base of 'technological knowledge' is the synergy of applied conceptual, procedural and tacit knowledge within the practical domain. However, defining conceptual knowledge as 'the body of content' (McCormick, 1996), may be too simplistic in terms other than the most general.

2.5.4. Conceptual Knowledge & Knowledge of Principles

The various definitions offered of the conceptual component of technological knowledge are arguably broad. Simply stating it as a body of content, for example, encompasses a vast range of knowledge types and could be seen to subsume such things as knowledge of principles and relationships, scientific or otherwise. Whilst it is unrealistic, and out with

[3] Whilst Sternberg defines tacit knowledge as procedural, it is recognised that all forms of knowledge have a necessary tacit dimension to them (*see* Polanyi, 1966).

the scope of this study, to distinguish between all possible forms of content knowledge, pertinent considerations made by Gagné (1966), suggest merit in defining conceptual knowledge and knowledge of principles more discretely.

By definition, ‘concepts’ are the result of constructs formed within an individual’s mind based upon their discrimination of aspects of the activity they are involved in. Gagné (1966), develops an important definitional distinction between 'concepts' and 'principles' borne from his concern with the “general, rough and imprecise” manner in which the terms concept and conceptual are used. He addresses definitions of ‘concepts’ through examining the work of several prominent researchers including Berlyne, Kendler and Carroll. In summation, Gagné argues that a concept possesses three general properties:

1. It is an inferred mental process.
2. The learning of a concept requires discrimination of stimulus objects (distinguishing ‘positive’ or ‘negative’ instances).
3. The performance which shows that a concept has been learned consists in the learner being able to place an object in a class.

He provides examples of this such as the learning of a chair as a class of object, or learning ‘red’ as a property of objects, which is detachable from particular objects. Furthermore, in discussing the external, often verbal, performance that indicates a concept has been learned, Gagné (1966) argues, in the case where the concept is the radius of a circle, that we would expect the learner to answer such questions as ‘show me a radius’ or ‘draw me a radius’ or picking a radius from a selection of alternatives. We would not, however, expect the learner to answer the question: ‘why is that line a radius?’ Gagné argues that for instances more complex than the discrimination of classes, learners have to demonstrate what he defines as a ‘principle’ or ‘rule’. In illustrating that learners can identify concepts but demonstrate principles, Gagné cites the principle of ‘work’ as force multiplied by distance. Here, it is argued that in order to demonstrate this principle, a learner must identify a member of the class ‘force’, a member of the class ‘distance’ and an instance of the class multiple and subsequently, that a principle is a relationship between two or more concepts. Gagné's resultant levels of knowledge are shown in Table 2.9.

Gagné's Knowledge Levels	
Knowledge Level	**Demonstrated By**
Stimulus Discrimination (lowest level)	The ability to recognise that two objects are different from each other
Conceptual Understanding	The ability to name an object within a class
Understanding of Principles (highest level)	The ability to demonstrate the relationship between two or more concepts

Table 2.9

Within this study, these considerations allow further clarification of the knowledge drawn upon during technological problem solving. Discrimination of objects and properties within recognised classes, for example, constitutes a central method by which pupils can "describe things as they are" (Vincenti, 1990). Similarly, a technological problem may have to draw upon the principle of turning moments within a mechanical system, again involving members within the classes of force and distance and this type of relationship is furthermore analogous to those found within technological laws. In other circumstances, the difference between concept and principle may be reflected in the extent to which something is described.

These distinctions allow the body of content within technological activity to be defined in terms of both conceptual elements and knowledge of principles & relationships discretely.

2.5.5. Procedural Knowledge & Knowledge of Principles

It has already been stated that the inter-relationship between each of the identified knowledge types is both fluid and exceptionally complex. Although the relationship between conceptual knowledge and knowledge of principles is more readily apparent, there is an argument that knowledge of principles also underlies processes. This is exemplified through the work of medieval blacksmiths who, through practical experience, were able to alter the physical properties of the metal such that it became optimal for use in crafting swords. By the assertions of Custer (1995), it could be argued that this 'practical experience' would have given rise to a cognitive base of technological knowledge once more allowing the sword's manufacture to take place void of the explicit application of 'scientific knowledge'. In contemporary material science, however, developments and adjustments of material properties are more often based upon the application of known scientific principles and mathematical models. This paradigm suggests that, as well as involving a shift from explicit to implicit knowledge, principles and relationships shape and influence procedural knowledge, even if they are not consciously applied.

2.5.6. The Form & Nature of Technological Knowledge

From the above discussion, it can be seen that application and utilisation of a range of explicit and implicit forms of knowledge in developing a practical solution gives rise to a base of 'technological knowledge'. The work of Ropohl (1997) and Frey (1989), demonstrate that this technological knowledge base is manifest in five identifiable forms illustrated in Table 2.10. The inclusion of a separate column for each author identifies theoretical analogies and it is recognised that pupils can only partially develop some aspects of these.

	Forms of Technological Knowledge as Defined by Frey & Ropohl		
	Termed by Frey	**Termed by Ropohl**	**Description**
Forms of Technological Knowledge	Artisan	Technical Know-How	Gained from experience only this has a high tacit content and low conceptual content.
	Technical Maxims	Functional Rules	Generalisations about skills applied in operating or making technology. They take the form of recipes, rules of thumb, sequences of operations and so forth.
	Descriptive Laws	Technological Laws	Empirical relationships that are established between variables with no scientific basis.
	Technological Theories		The systematic relation of a number of technological/descriptive laws.
		Socio-Technological Understanding	Systemic knowledge of the inter-relationship between technical objects, the natural environment and social practice.

Table 2.10

It is argued in this thesis, that building up experience in solving technological problems that require pupils to move from concept to artefact will develop their technological knowledge and capability. It is also recognised that the knowledge pupil can draw upon and the sources thereof, is different from that of expert problem solvers.

2.6. Sources of Knowledge for Technological Problem Solving

Sections 3, 4 and 5 explored each of the strands of technological problem solving in turn. Four modes were identified within which a range of intellectual processes and knowledge types may be drawn upon by pupils in the course of solving a technological problem. This section ties this to the context of classroom problem solving by exploring and identifying the sources of knowledge available to pupils when undertaking technological problem solving.

The following knowledge sources are identified in the proceeding discussion:

- Task Knowledge
- Prior Technological Knowledge
- Prior Personal Knowledge
- The Developing Solution
- Classroom Teacher

All of these knowledge sources form part of the analytical framework that is coded for within Chapter 6. The way in which they are conceptualised here shapes the way in which pupil activity during problem solving is represented and the subsequent investigation thereof.

2.6.1. Objective & Subjective Knowledge

Herschbach (1995) argues that technological knowledge is "a compendium of information to be transferred to the student that is only truly realised as technological through its application in practical activity." This is congruent with the aforementioned discourse on the epistemology of technological problem solving. DeLuca (1992), states that in its simplest form, technological problem solving involves the application of recalled knowledge which may come from learning that has taken place within the technology class, or from related learning out with. From a differing perspective, Twyford & Järvinen (2000), through their own empirical study, identify the individual pupil as a source of 'personal knowledge'; knowledge that is unique to an individual’s experience both during problem solving and from out with the task environment.

Many conclusions can be drawn from the above assertions, however, the arguments levelled by Twyford & Järvinen (2000) and Herschbach (1995) have their foundations within two distinctly separate conceptual paradigms. Herschbach, through his notions of knowledge transferred to the pupil, and then to the practical activity is implying a fairly high degree of objectivity; a central tenet of the modernist knowledge paradigm. This paradigm is defined by Schreiber & Moring (2001), as one in which knowledge is seen to objectively exist out with the human being and which is made explicit only through its capture in some kind of medium such as a book. Jonassen (1991), argues that this assumes all knowledge is reliable and can simply be transferred between teacher and pupil. Twyford & Järvinen (2000), however, through stressing the uniqueness that can be seen in an individual's knowledge, align their assertions within the post-modern paradigm. Schreiber & Moring (2001), argue this paradigm views knowledge as a socially constructed and on-going process where the expression of knowledge constitutes a social construction and can therefore never be viewed as an objective entity. In compliment to this, Salomon (2000), makes the semantic distinction when discussing 'information' as being that which is discrete and relatively context independent, though 'knowledge' he argues, is embedded in context and is internally arranged in networks with meaningful connections between nodes. This is concurrent with constructivist, as well as cognitive neuro-scientific, notions of knowledge building (*see* Ernest, 1995).

There are several schools of thought advocating varying extremes of how knowledge can be conceptualised within the subjective-objective continuum. For example, Sutton (2001), describes a radical subjective view-point which advocates our only method of directly knowing something is through our senses and interaction with the environment. Furthermore, 'metaphysical idealism' denies the existence of the physical out with our own minds: a view that can lead to numerous conceptual paradoxical inconsistencies (*see* LaFave, 2003). Conversely, 'metaphysical objectivism' argues there is a discrete reality, which exists entirely independently of consciousness (King, 2004). 'Transcendental Idealism' encompasses aspects of both doctrines arguing that knowledge equates to a correspondence between subjective perception and objective reality (*see* Alison, 2004; Scott, 2001). Philosophical exploration of this vast range of definitions of knowledge is out with the scope of this thesis however, perspectives from these are drawn upon in defining sources and types of knowledge relevant to technological problem solving within classrooms.

2.6.2. Knowledge Sourced from Learning & Teaching within the Technology Class

Erkip et al (1997), present a model of knowledge sources for designers in which many parallels to classroom-based technological activity can be seen. The model presents 'media', 'community' and 'domain' as three sources from which knowledge can be drawn. Table 2.11, adapted from Erkip et al, 1997, outlines these and lists the parallels that can be drawn with technology classrooms.

Knowledge Sources Identified by Erkip et al (1997)		
Knowledge Source	**Ascribed Elements**	**Classroom-based Equivalent**
Relevant Media	Text, diagrams and other material	Similar, and can include those things given to or researched by the pupil.
Relevant Community	Authorities, experts, clients (Should be transferred without distortion)	Analogous to the education system, curriculum, teacher and task.
Relevant Domain	Instrumentation, observations and modelling (designer's previous experience)	Pupils prior learning and 'technological' knowledge.

Table 2.11

Moreover, aspects of this are further developed by Sveiby (1997), cited in Lou et al (2010), who describes 'relevant media' and 'relevant community' as 'indirect' and 'direct' forms of knowledge respectively. Relevant media can be conceptualised as knowledge that is externally reliable under the modernist paradigm. Erkip et al, argue the relevant community should be similar to this, whilst the prior knowledge component can be conceptualised as largely subjective under the postmodernist paradigm. Beyond these analogies, however, the dynamics of knowledge within a technology class are enormously complex and it is out with the scope of this study to examine the fine minutiae therein. Subsequently, through exploring some illustrative examples, the case is made that a pluralist knowledge dynamic exists (Finn & Ravitch, 1996), whereby both objective and subject classroom knowledge can be drawn upon by pupils during problem solving.

Anning et al (1996), highlight a distinction made by David Barlex regarding the knowledge pupils require to undertake a technological problem solving activity, in which he argues that they require both knowledge of the problem and knowledge of the solution. The former may involve learning about such things as the demands of the brief, who it is for and where it will be used; discussed by Davidson et al (1994) in terms of what is known, what is unknown and what is required. The latter is associated with the related technologies, materials and products that can be employed. Within each of these considerations, subjective and objective elements of knowledge can be identified. For example, any constraints within the problem brief, which amount to information regarding the initial state (Mayer, 1992; Davidson et al, 1994), should ideally be transferred to the solving process 'without distortion' (Erkip et al, 1997). In this sense, this knowledge can be argued as 'objectively transferred' but will be manifest in a practical manner in accordance with the assertions of Herschbach (1995). However, it may be that the pupil undertakes an exploration of material properties guided by the teacher (*see* Bruner's *Hypothetical Mode*, 1961). Here, the processes involved are more 'constructivist' than 'instructivist' whereby the pupil is seen as the active constructor of their own knowledge and understanding through progressive social interaction rather than a passive receiver thereof (Schwandt, 1994; Bruner, 1961). The complexity of this process is engendered by the notion that one pupil will construct understanding and knowledge that is slightly different from the next, in a sense, rendering it both personal and subjective.

Whilst these three sources account for knowledge that is most immediate to classroom-based problem solving activity, that knowledge which pupils bring from out with the classroom environment constitutes another important form of personal knowledge. This knowledge is again subjective and unique, irrespective of the minutiae that render it different, however, according to Taber (2001), this, in itself, can prove problematic. He describes cases where pupils bring such personal knowledge to classroom learning that is inaccurate or incorrect and, moreover, can be exceptionally difficult for pupils to 'un-learn' and can lead to the construction of spurious meanings. Further to this, Jonassen (2000), argues that such misrepresentations are one of the core reasons for pupils apparent inability to transfer problem solving skills to new and novel contexts.

2.6.3. The Developing Solution as a Source of Knowledge

This arguably constitutes a distinct source of knowledge during the problem solving activity in that it changes over time, and thus can be considered 'dynamic'. Essentially, this source of knowledge evolves from interactions between the pupils and the solution. Hamel & Elshout (2000), comment on the apparent periods during problem solving where one might conclude limited progress is being made and purport that, in fact, these periods may be indicative of a gradual development of knowledge by the solver. The notion that knowledge is developed as a function of engaging in problem solving is widely recognised and central to learning (*see* Hayes, 1988; Roschelle & Teasley, 1994; Hamel & Elshout, 2000). Davidson et al (1994) argues, through examining the role of meta-cognition in problem solving, that there are four mechanisms that aid in solving problems:

1. Identifying and defining the problem
2. Representing the problem
3. Planning how to proceed, and
4. Evaluating what you know about your performance

Clearly, all of the above play an active part in problem solving, however, in this context, it is the solvers representations that are directly tied to the developing solution as a source of knowledge. Hayes (1981), states that individuals change and develop their mental representations during the course of problem solving as a result of the solver discovering new knowledge that was not available or known to them before. This is partly achieved through the process of 'encoding', previously identified in the work of Marzano et al (1988), however, Hayes (1981), also describes how representations arise through this, and the two additional processes of 'combination' and 'comparison'[4] as shown in Table 2.12.

Processes that Develop Mental Representations	
Cognitive Process	**Description**
Selective Encoding	Identifying in a stimulus, or set of stimuli, one or more relevant features that previously have been non-obvious.
Selective Combination	Putting together elements of a problem situation in a way that previously has been non-obvious to the individual.
Selective Comparison	Discovering a non-obvious relationship between new information and information acquired in the past.

Table 2.12

[4] It is recognised that there are numerous theories that account for encoding and knowledge acquisition, the exploration of which is out with the scope of this thesis. The most prominent of these theories include, but are not limited to: Genetic Epistemplogy and the

The role of encoding, combination and comparison stresses the link that exists between the mental processes identified by researchers such as Halfin (1973), and the pupils' construction of personal knowledge during problem solving. It is reasonable to suggest that as pupils move through such cyclic, iterative models as those proposed by Mioduser & Kipperman (2000), and Scrivener et al (2002), that they will continually construct and modify mental representations of aspects of the developing solution, including those subconscious and more tacit aspects of practical activity (*see* 'Motor Skills Model', Argyle 1967). It can be seen that this process is essential for pupils to progress through technological problems, accumulate practice and ultimately build their technological knowledge base.

2.6.4. Peers as a Source of Knowledge

In situations where pupils engage in collaborative problem solving, their peers will also constitute a source of subjective knowledge. Ploetzner et al (1997), discusses this in a study exploring the sharing of knowledge and representations by dyads solving problems in classical mechanics. The importance of knowledge through discussion is underscored by a range of studies (e.g. Bennette & Cass, 1989; Glass, 1990; Webb 1983; Mercer, 1996). Moreover, Hendley & Lyle (1995) stress that discussion between pupils is essential to promoting a range of technological problem solving skills.

2.6.5. Defining Knowledge Sources for this Study

Based on the preceding discourse, and for the purposes of this study, four sources of knowledge are defined with respect to a given instance of pupils engaging in technological problem solving. Each of these is described as follows:

Knowledge Source 1: Task Knowledge

Knowledge that is associated with the given problem and solution gained within the context of the technology classroom and which is applied or used in some way during problem solving. This knowledge source is objective in nature and, under ideal circumstances, it is anticipated that this would remain as such even when employed within the problem solving process.

---

processes of assimilation and accommodation, Piaget, J. (1929); Modes of Learning and the processes of 'accretion', 'structuring' and 'tuning', Rumelhart, D. & Norman, D. (1978); Subsumption Theory, Ausubel, D. (1963).

Knowledge Source 2: Prior Knowledge of the Pupil

This is knowledge previously constructed by the pupil and is hence a subjective source in problem solving. The pupil in question or a peer can constitute a source of prior knowledge. For the purposes of this study, prior knowledge of the pupil has been broken into the following two sub-sources:

1. Prior Technological Knowledge
   This is knowledge from previous learning and accumulated practice within the technology class and from previous technological problem solving (see Conceptual Model of Technological Problem Solving, Section 2.7, Figure 2.12).

2. Prior Personal Knowledge
   This is prior knowledge from experiences and learning out with the technology class encompassing that which was acquired in other curricular areas and out with the school context.

Knowledge Source 3: The Developing Technological Solution

This is an objective, but fluid and dynamic source of knowledge, the properties of which will change as pupils move through the problem space.

Knowledge Source 4: The Technology Teacher

As an expert within the context of a technology classroom, and in accordance with the assertions of Erkip et al (1997), the teacher should be considered an objective knowledge source.

It should be recognised that whilst these constitute sources of knowledge that a pupil could draw upon when solving a technological problem, they do not claim to account for the ways in which pupils apply different types of knowledge to the problem. As already discussed, research suggests that there are difficulties associated with pupils' ability to transfer knowledge between different tasks and contexts. Jones et al (1995), for example, concluded that pupils find great difficulty in transferring learning from science class to technology problems which, in turn, indicates that pupils may find it hard, or choose not, to apply prior personal knowledge when problem solving in technology (*see also* Perkins &

Salomon, 1998).

2.7. Section 7 – An Original Conceptual Model of Technological Problem Solving

The preceding sections of this chapter develop a three strand definition of technological problem solving for secondary school classrooms and consider the knowledge pupils have access to in facilitating the development of a solution. This definition comprises of problem solving mode, intellectual processes and epistemology. This section presents an original conceptual model of technological problem solving (Figure 2.12) based upon a synthesis of salient features and concepts from the preceding discussion.

The following conclusions drawn from discourse throughout the conceptual framework, form the theoretical basis for the model in Figure 2.12:

1. The proposed model applies to all four identified modes of technological problem solving as long as the solution is, or is manifest within something which is, physical and tangible.
2. Technological activity is not merely applied scientific knowledge, however, there are instances where knowledge of principles and relationships are applied, or transformed, when solving technological problems.
3. There are identifiable elements of conceptual-descriptive knowledge and procedural knowledge involved in technological activity.
4. Knowledge of principles and relationships, from a range of areas, influence both conceptual and procedural aspects of technological activity.
5. An implicit, procedural, tacit knowledge can be identified which relates to an individual's judgement and skill. As the level of mastery/experience increases, the more implicit the procedural knowledge becomes.
6. Technological knowledge arises from and is embedded within the application of other forms of knowledge towards a practical end.
7. Different types of knowledge are applied and transformed through the use of a range of intellectual processes by pupils when moving towards a practical solution.
8. The intellectual processes that pupils draw upon will depend upon the pupils themselves, the mode of problem solving, the sources of available knowledge and the nature of the developing problem solving endeavour.
9. Because of its relationship to science, and the necessity to produce a physical solution, classroom technological problem solving relies neither on wholly

theoretical knowledge, nor on wholly practical knowledge. Between these two extremes, it is possible to locate the underlying principles, conceptual and procedural knowledge which, when applied and transformed through accumulated practise, would typically give rise to technological knowledge.

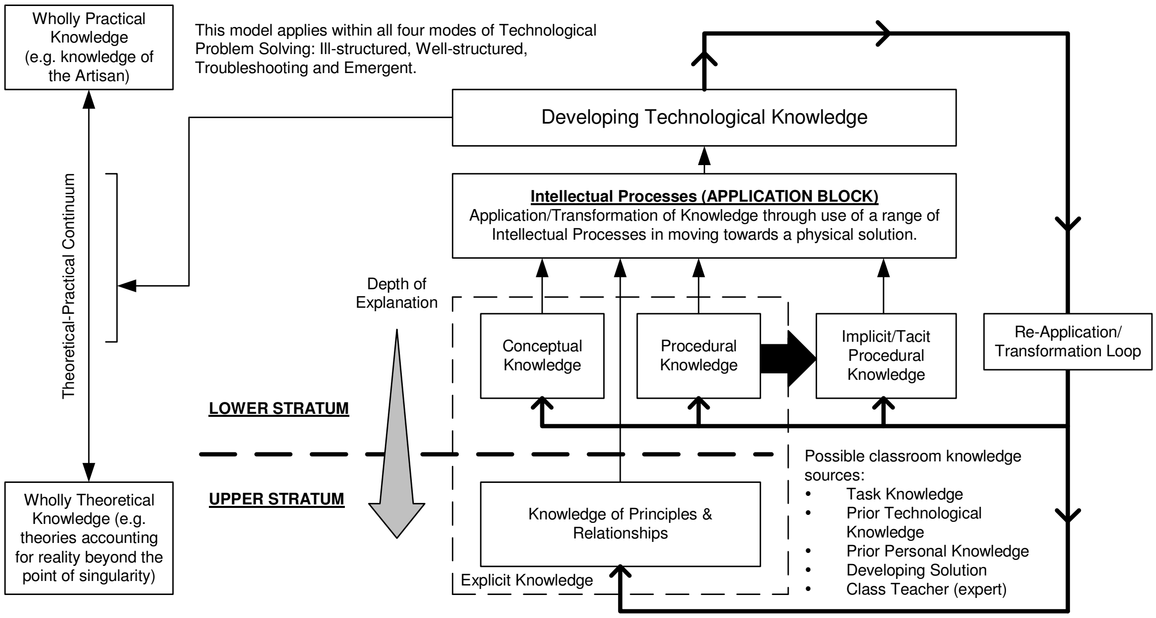


Figure 2.12 – A Conceptual Model of Technological Problem Solving for a Given Mode

The original conceptual model presented above is cyclic in nature, indicative of an individual's accumulated practice. The more often an individual moves through this cycle, the more implicit elements of procedural knowledge becomes and the more developed their technological knowledge base will become.

This model forms the conceptual basis for the proceeding investigation within this study; however, its complexity is such that it cannot be fully explored within a single study. In the application block, for example, there may be upwards of thirty processes present and the complexity would be further compounded by the scale at which these are examined. Though this is fully described and evidenced in Chapters 3 to 6, this study employs a range of strategies to achieve the necessary focus. Firstly, the study considers the model within only one of the four problem solving modes. Secondly, the study is designed to focus only upon areas where differences are present and disregards those that are similar between participating pupil groups. In comparing the problem solving activity of pupil groups against task performance, it is shown that there are key differences within the application block, the use of conceptual knowledge and knowledge of principles and relationships and in the implicit/tacit procedural knowledge element (see Chapter 6 for the analysis and Chapter 7 for these specific results).

However, the following chapters demonstrate how this study identifies and explores those elements from the model that are involved in group differences within one of the four modes (well-defined problem solving). In comparing groups, 'areas of difference' are identified in both the use and depth of knowledge and in the nature of the intellectual processes.

2.7.1. The Relationship between Knowledge Sources & the Conceptual Model of Technological Problem Solving

Table 2.13 illustrates the relationship between the sources of knowledge just defined and the types of knowledge identified within the epistemological model. The purpose of the map is to indicate those types of knowledge that each source could potentially provide during technological problem solving.

Knowledge Sources vs. Conceptual Model of Technological Problem Solving.					
Knowledge Source	**Form**	**Conceptual**	**Explicit Procedural**	**Implicit Procedural**	**Concepts, Principles, Relationships**
Task Knowledge	Objective	✓	✓		✓
Developing Solution	Objective	✓	✓	✓	✓
Classroom Teacher	Objective	✓	✓		✓
Pupils (Prior Technological)	Subjective	✓	✓	✓	✓
Pupils (Prior Personal)	Subjective	✓	✓	✓	✓

Table 2.13

The aforementioned discussion of knowledge types, sources and the conceptual models developed within serve to clarify and substantiate the definition of technological problem solving developed within this study. However, this form of problem solving, by its very nature, is complex, fluid and characteristically varied and the role of knowledge within is hence similarly fluid. As such the epistemological assertions made here cannot be regarded as definitive for all problem-solving situations in accordance with Vincenti (1990), who argues that there are always exceptions and occurrences that do not firmly adhere to categorisation.

2.8. Chapter Summary

This chapter began by exploring the general understanding of problem solving developed within the fields of 'Behaviourism', 'Information Processing & Cognitive Psychology', 'Intelligence Theory' and 'Situated Cognition'. This described respective core contributions including trial and error, the information processing model, components of successful intelligence and thinking with things; the latter of which is closely linked to pupils' technological activity. Following this, a three-strand definition of technological problem solving was developed in terms of 'mode', 'intellectual processes' and 'epistemology'. Four modes were established from the literature: ill-defined, well-defined, emergent and discrete troubleshooting, each of which was seen to employ a broad range of intellectual processes and forms of knowledge; the nature of which was dependent upon the pupil, the task and the context. Ultimately, the core concepts within each of these strands were synthesised into an original model of classroom technological problem solving, the context for which was grounded through consideration of the knowledge sources available to pupils during such activity. The conceptual model was argued to apply within each of the modes the cyclic nature of which promoted the development of pupils' technological knowledge base.

Chapter 3 sets forth the research question and associated epistemology for this study. The question is based directly upon the conceptual framework, channelling the proceeding exploration of technological problem solving activity in terms of intellectual processes and knowledge within the 'well-defined' mode of problem solving. The associated epistemology sets forth the philosophical approach through consideration of the question and the nature of the phenomena involved.

Chapter Three

Epistemology of the Study

3. Epistemology of the Study

Chapter 2, the conceptual framework, develops a definition of technological problem solving in terms of mode, process and epistemology and presents an original conceptual model thereof. This chapter sets forth the main research question and defines the epistemic stance the study adopts in exploring it. The research question is established through consideration of the conceptual framework and the associated research, and the epistemic stance is defined through an examination of positivist and post-positivist research paradigms. As such, this chapter provides the foundation on which the proceeding inquiry is based and a rationale that informs decisions regarding the design of the study.

3.1. Development of the Research Question

The research question for this study is defined through the following three areas of consideration:

- The Conceptual Framework
- The Unit of Study
- The Wider Context for this Research

Each of these is discussed below.

3.1.1. The Conceptual Framework

The conceptual framework established a definition for technological problem solving for the purposes of this study. Within this, the procedural and epistemological dimensions are conceptualised along with four different modes of problem solving associated with a practical outcome. Of these modes, discrete troubleshooting is not a requirement of the guidance on the curriculum in Scotland, and emergent troubleshooting (or problem solving) can arise within a range of problem solving modes. Furthermore, it is shown that a good deal of the research undertaken concerns the nature and benefits of the more open-ended forms of technological problem solving. As it is out with the scope of this study to explore all of the identified modes, the focus is restricted to exploring technological problem solving activity in response to more defined problems. In accordance with the conceptual framework, this is done in terms of process and knowledge.

3.1.2. The Unit of Study

Although changes may arise as a result of the most recent curricular reform (*see* A Curriculum for Excellence), historically, and currently, activities in the form of 'design-and-make' are normally undertaken as individual pupil tasks within Scottish Technology Education Departments. Despite many of the research studies cited within the conceptual framework focusing on dyads and small groups, this is still a relatively unusual approach within most departments. As such, this study defines the small group, rather than the individual pupil as the unit of study.

3.1.3. The Wider Context for this Research

A great deal of the research cited within the conceptual framework gives insight into the intellectual processes used by pupils, the tendencies of novice designers and the differences that exist between them and expert designers. There have been studies that show the different routes taken by pupils when solving technological problems and the relationships that are likely to exist between the type of activity and the type of problem. This study augments these findings, and others, by focussing specifically upon establishing the differences in process and knowledge associated with producing more successful and less successful technological solutions to a given problem.

3.2. The Research Question

In terms of intellectual processes and knowledge, what are the differences in the modi operandi between groups of pupils that produced more and less successful technological solutions to a well-defined problem?

3.3. Developing an Epistemic Rationale for the Study

Olson (1995), discusses the importance of researchers clearly identifying the epistemic stance and considerations in their studies. This author would argue that this is imperative for two reasons. The first is that this shapes the foundation that determines to a large extent how methodological issues are addressed and dealt with and ultimately, how claims of knowledge are made. The second is because this is a Doctoral Thesis in Education. This author has come to realise that 'Educational Research' is a sphere of activity that can be seen to share a striking parallel with school-based technology education. Discussion within the Conceptual Framework has shown that the intellectual domain of technology is not as easily defined as it is for some other fields such as mathematics, and pupils in technology classes draw upon knowledge from various different subjects and sources when shaping a technological solution. A very similar mechanism can be observed to operate within educational research. As a sphere of activity, it does not have its own defined set of methods and approaches as can be found within other research disciplines such as natural science, geology, statistics, ethnography, engineering or psychology. Instead, it draws upon approaches from other areas, such as social sciences and psychology, to inform on the processes of learning and teaching. Because of this, defining an epistemic stance within Educational studies is arguably more important than it is for many other disciplines.

Rather than adhere in totality to any one investigative approach, this study draws upon a range of methods as appropriate to the phenomena under investigation and the question being asked of it. The following chapter describes the resultant stance of methodological eclecticism adopted within this thesis. It should also be noted, however, that two distinct aspects of this study reflect some of the approaches found within 'Grounded Theory' (*see* Glaser & Strauss, 1967). The first is that the conceptual framework explores related concepts but makes no prediction as to which will be involved in the differing levels of task performance. The second is that the initial analytical phase described in Chapter 6 is heavily inductive in nature. A fuller discussion of the analytical approach and grounded theory is found at the beginning of Chapter 5.

The following sections describe the development of the epistemic stance of the study beginning with the positivist and post-positivist paradigms.

3.3.1. The Positivist & Post-Positivist Paradigms

Gall et al (2002), discuss the positivistic and post-positivistic philosophies in relation to natural enquiry. They contend that the central school of logical positivism is driven by objectivity and meaningfulness attained only through observations by the human senses as defined within the verifiability principle (p.17). This can be argued as the basis for much of the behaviourist-based research carried out within education. However, they also go on to describe the post-positivistic philosophy derived from contentions with four of the main assertions of the positivist approach: theory-free and value-free observation, validity by observation only and degree of generalisation (p.18).

(1) Theory-free observation: Whilst the positivist school of thought asserts that the variables under question should be observed objectively and devoid of the theory they are designed to test, post-positivists argue that this simply is not possible, and that close examination of any observational strategy reveal that it is, in-fact, laden with theory.

(2) *Value-free observation*: Positivist thinking purports that in order that the observations employed in testing claims about knowledge are in no way reflective of the researcher, the observations must be free of values. Again, post-positivist thinking argues this is not possible in that social research itself is driven largely by value sets and, furthermore, that the very concepts employed by social research are 'evaluative' of human behaviour.

(3) *Validity by observation only*: This relates to the positive notion that validity can only be attained by objective observation. Post-positivist thinking argues that this is insufficient to account for many of the social factors that are deemed of importance to education such as intentions, feelings, cognitions, climates and values. It posits that no reason exists to deem these factors any less real than purely observable ones.

(4) *Degree of generalisation*: Positivism dictates that findings confirming one hypothesis measured in one setting at a given point in time are equally valid in other settings at other points in time. Post-positivism refutes this in any application within the natural world. It recognises that there can be extreme variability between individuals, groups and cultures that must be acknowledged and, where possible, accounted for.
(Gall et al, 2002)

3.3.2. Knowledge Claims & Methodological Epistemology

As shown in the following chapters, this investigation produces appropriately verified claims of knowledge, and presents an original contribution to knowledge. Clarke (2001), defines knowledge as *"a body of facts and principles accumulated by mankind in the course of time"*, and moreover, epistemology as the study of knowledge, its sources, varieties and limits. Within epistemology, empiricism represents the notion that knowledge is derived from experience; the extreme of which is manifest in logical-positivism (Cohen et al, 2000; Gall et al, 2002). The opposite notion is represented by apriorism, contesting that knowledge is innate; the extreme of which denies the existence of knowledge out with the individual's mind (Clarke, 2001). The relevance in sourcing the intended investigation within this spectrum is catalysed by the ontological issues associated with such things as inferring cognitive or intellectual activity from observable behaviour; processes which, themselves, cannot necessarily be seen by the naked eye. This is considered by Sober (1993), who discusses ‘direct’ and ‘in-direct’ knowledge. Through an analogy of research into atoms, he concludes that the only way knowledge can be gained about the unobservable is to find out about the observable, and that all knowledge of the unobservable is necessarily indirect. However, the most important aspect of these assertions is that some form of judgment must be made by the researcher, the integrity of which is largely measured through the detail and transparency of the experimental design.

A further layer of related consideration surfaces through re-examining the positivist and post-positivist doctrines in conjunction with constructivism within social science. Whilst Sober (1993), provides a useful distinction between 'direct' and 'indirect' knowledge in an empirical sense, probing deeper into knowledge that is 'inferred', or derived through interpretation, feeds into *‘objective’* and *‘constructed’* conceptions of reality.

Gall et al (2002), discuss *‘objective reality’* and *‘constructed reality’* in relation to educational research. Objective reality is a tenet of positivist thinking which decrees that features of one's social environment exist independently of the individual who creates or observes them. This would suggest, for example, that the social and physical reality under investigation operate independently from the researcher's presence. Conversely, the post-positivist tenet of constructed reality purports that ‘social reality’ is constructed by the individuals who take part in it. As Gall et al explain, these constructions result from assumptions an individual makes about the social environment. From this constructivist point of view, the researcher is not only part of, but also constructing his own interpretations of, and influencing other people's interpretations of, the social environment. Subsequently, it can be argued that knowledge relative to the researcher may not only be 'direct' or 'indirect', but also subject to influences by his or her very presence. Acknowledgement of this type of occurrence is sometimes addressed through the process of ‘reflexivity’, where direct account is taken of the researchers role and actions within the study environment (*see* Breuer et al, 2002). Doing so is, in many ways, accepting that ‘experimental’ settings of this nature elicit a degree of uniqueness that renders arising findings more difficult to validly apply through time and place. Its place within many studies is as a result of the post-positivist assertion that interpretive studies must be carried out at a local and immediate level, and a necessity to appropriately substantiate the interpretations made (*see* Boulton & Hammersley, 1996; Mason, 1996 in Mauthner &

Doucet, 2003).

Furthermore, it is necessary to acknowledge that the role of interpretation is not confined to the environment in which data gathering takes place and can be seen as manifest throughout the entire research process. Gall et al (2002), discuss in detail the 'consequences' of the post-positivist doctrine (p.16). The level of attention found in discourse about qualitative stances, data gathering and analytical techniques highlights the importance in making considerations about methodology (*see* Bong, 2002; Faux, 2000; Mayring, 2000). Gall et al (2002), demonstrate that the researcher may, for example, interview a participant in order to ascertain his or her constructions of social reality. However, the success of this can be marred by the constructions the participant makes of the researcher during the interview. A further level of complication is introduced when the researcher reports upon his or her findings: a construction made by the researcher, of which the degree of objectivity can be further lost when the readers of the report make their own constructions (p.16). While aspects of this could arguably be true for research or literature of any form, additional considerations and measures must be taken in more qualitative and interpretative form of inquiry.

3.3.3. This Study within the Positivist & Post-Positivist Paradigms: The Case for Methodological Eclecticism.

Under the positivist and post-positivist philosophies have grown two distinct methodological paradigms: quantitative and qualitative respectfully (Gall et al, 2002). Often referred to as ‘experimental’ and ‘non-experimental’ methods (Hammersly, 1996), their characteristics define opposite ends of a paradigmic continuum (Bazeley, 2004), although they are often implicitly discussed as dichotomous within literature. Olson (1995), argues that beyond the underlying ontological and epistemic assertions of each paradigm, the differences are often more subtle and that drawing a definitive line between each is not necessarily appropriate. He further suggests that, in many cases, differences between the two are down to where emphasis is placed; objective researchers striving to reduce it, subjective researchers striving to appropriately acknowledge it – they still, however, both recognise and deal with bias. Bryman (1988) provides a comparison of the different approaches associated with each end of the continuum as shown in Table 3.1. The differences are considered against eight separate measures.

Whilst these considerations provide some quite stark distinctions, it is also apparent that large and complex studies do indeed draw upon characteristics of both and to different degrees depending upon the phenomena under investigation and the nature of the aspects thereof. Moreover, different approaches could be taken to exploring aspects of the same type of phenomena. In examining pupils' technological problem solving, Welch & Lim (2000), categorised problem solving processes through a largely quantitative mechanism, whilst in a study carried out by Roden (1997), qualitative analysis of pupils speech was employed in an attempt to ascertain pupil's motivations as they moved through the solving process.

Qualitative & Quantitative Approaches		
Measure	**Quantitative (experimental/positivist)**	**Qualitative (non-experimental/post-positivist)**
(1) Role of qualitative research	Preparatory	Means to explorations of actor's interpretations
(2) Relationship between researcher and subject	Distant	Close
(3) Researchers stance in relation to subject	Outsider	Insider
(4) Relationship between theory/concepts and research	Confirmation	Emergent
(5) Research Strategy	Structured	Unstructured
(6) Scope of Findings	Nomothetic	Ideographic
(7) Image of Social Reality	Static and external to actor	Constructed by actor
(8) Nature of data	Hard, reliable	Rich, deep

Table 3.1

It is also possible that both of these may feature within one study insofar as data gathered through a qualitative instrument such as observation, is then analysed using a qualitative approach (*see* Teddlie & Tashakkori, 2006). These differences may be engendered by such things as the context and framing of a given study, as well as the types of knowledge claims it intends to produce.

In order to address the research question, this study will necessarily gather data on pupil learning processes within technology classrooms and, although there is an associated conceptual framework, this dimension of the research question is exploratory in nature. In addition to this, the developing technological solution is a practical, tangible artefact that is also integral to the research question but which presents a more constant and objective data source than pupil interaction. Although both of these core elements are essential within this research, the pupil processes and the associated approaches constitute the more dominant dimension of study. It is therefore the case that findings from this research will be largely emergent and, when considered against the eight measures in Table 3.1, the overall approach will be non-experimental/post-positivist in nature. This is hence an interpretive study that employing a range of methods and approaches, qualitative or quantitative, which are appropriate to the different dimensions of those phenomena under investigation. The 'emergent' aspect is again similar to facets of grounded theory.

This approach is reflected in the proposals made by Hammersly (1996) who argues that, in fact, qualitative and quantitative measures can be employed to compliment each other within a study, where appropriate, depending on the focus, purposes and circumstances of the research. Hammersly argues this as a type of 'methodological eclecticism' where a combination of both methods is employed; often to cancel out identified weaknesses within each. Similarly, in Hoepfl (1997), Patton (1990) argues in preference of a "paradigm of choice" with methodological appropriateness at its heart.

This study, although interpretive in its overall nature and approach, subscribes to this case for methodological eclecticism, and employs several varied approaches to provide richer data about the phenomena under investigation. In accordance with Howe & Eisenhardt (1990), these are selected based upon how well they inform the purposes of the study rather than how well they match a set of conventions. Notably, Meetoo & Temple (2003), make two arguments in relation to this. Firstly, they acknowledge that qualitative and quantitative data cannot always simply and 'unproblematically' be combined to enhance a study, and secondly, they state that multiple methods, when used appropriately, can enhance validity. The latter of these points is further discussed in the proceeding sections and judgements regarding the appropriateness of methodological approaches are, by necessity, made in light of the developing study. This adopted approach is intended to yield greater insight and deepen the understanding of the phenomena under study in much the same way as reported by Russek & Weinberg (1993) in Hoepfl (1997) in their study of technology classroom resources. Moreover, with specific regard to research within

Technology Education, Hoepfl notes that from the 220 papers that were reviewed by Zuga (1994), only 16 employed qualitative methodologies and henceforth argues that more studies within this arena should employ mixed method approaches.

3.3.4. Rigour and Methodological Measures

In light of the preceding discussion, a robust methodological rationale must take cognisance of the four core measures involved in assuring rigour in quantitative or qualitative studies. These measures form a suite of necessary considerations that should form part of any given research study, although because Educational research has been historically dominated by the positivist paradigm, the measures in question are most widely referred to using positivist terminology: Internal Validity, External Validity, Reliability and Objectivity. The positivist definitions for each of these are given by Lincoln & Guba (1985), in Robson (1993), and are shown below:

Internal Validity
A measure of the extent to which a study can clearly show that the outcome was as a result of the treatment.

External Validity
Sometime regarded as working in opposition to internal validity, it is concerned with the extent to which findings can be shown as applicable to similar populations.

Reliability
A measure of the replicability over time and is concerned with precision and accuracy. It is a necessary facet of validity.

Objectivity
The extent to which findings are arrived at independently of any biases the researcher might have.

Although these distinguish four main groups of measures, there are many more aspects and forms to each that will be less or more relevant depending upon the nature of the study (*see* Gall et al, 2002; Robson, 1993). Whilst these are traditionally associated with quantitative studies, Cohen et al (2000), note that there is conceptual cross-over and assert, for example, that the concept of validity is a facet of both quantitative and qualitative approaches. Just as the post-positivist paradigm itself arose from contentions with the positivist school of thought, analogous measures for more qualitative studies arose from contentions with each of the four measures above evolving a range of alternative conceptions.

These variations are the result of the translation of each concept into the post-positivist milieu and the differing ways in which they are hence accounted for and manifest within research. As part of a discussion on the Case Study Method, Lincoln & Guba (1985), in Robson (1993), present four necessary aspects common to both quantitative and qualitative studies; they are, however, manifest differently. Each aspect is defined below and Table 3.2 (Page 83) describes how they are understood by the respective paradigms.

Truth Value

How can one establish confidence in the truth of the findings of a particular enquiry for the persons with which, and context in which, the enquiry was carried out?

Applicability

How applicable are these findings to another setting or group of people?

Consistency

How can one have confidence that the findings could be replicated if the study were repeated with the same (or similar) persons, in the same (or similar) situation?

Neutrality

How can we be sure that the findings are determined by the respondents and the situation and context, and not by the biases, motivations, interests or perspectives of the enquirer?

Robson (1993), argues that, collectively, these four elements allow a judgement to be made as to the 'trustworthiness' of a given study and, although the context is that of the Case Study, it recognises that these, and the concept of 'trustworthiness', are seen as common to all approaches.

When considering 'trustworthiness' in either paradigm, it is not difficult to appreciate the fact that these four measures are linked and exhibit a notable degree of interdependence. Low measures of reliability are at risk of also lowering the external validity, and this reliability could be low due to bias and a lack of objectivity. Within this, reliability is an obligatory, but on its own, insufficient component of validity. This being said, it is arguably the case that virtually all conceivable measures within any given study are ultimately part of, and shape, validity and reliability. It is in regard to these two fundamental measures, that Cohen et al (2000), state two important facts. Firstly, that validity and reliability are 'multifaceted' and must hence be addressed in a variety of ways and, secondly, that threats to the validity and reliability of a study cannot be completely removed, only attenuated by suitable attention throughout (p.105).

Methodological Aspects as Understood in Quantitative & Qualitative Research		
Aspect	**Quantitative Domain**	**Qualitative Domain** (Lincoln & Guba)
Truth Value	INTERNAL VALIDITY A measure of the extent to which a study can clearly show that the outcome was as a result of the treatment.	CREDIBILITY Demonstration that the enquiry was carried out in a way that ensures the subject of the enquiry was accurately identified and carried out. This may involve enquiry over extended periods, triangulation or peer debriefing.
Applicability	EXTERNAL VALIDITY Sometimes regarding as working in opposition to internal validity, however, is concerned with the extent findings can be shown to be applicable to similar populations.	TRANSFERABILITY The extent to which findings can be generalised to other similar populations. Central to this is the provision of all necessary sample information such that a detailed understanding can be gained as to its nature.
Consistency	RELIABILITY A measure of the replicability over time and is concerned with precision and accuracy. It is a necessary facet of validity.	DEPENDABILITY A necessary, but not sufficient component of credibility. The extent to which measures are consistent. This may involve strategies such as triangulation or enquiry audits carried out by persons other than the main enquirer.
Neutrality	OBJECTIVITY The extent to which findings are arrived at independently of any biases the researcher may have.	CONFIRMABILITY The focus here is not so much on whether or not the researcher is objective or not, but rather if the case study itself supports objectivity. It is therefore necessary to provide sufficient information so that the adequacy of the process and the extent to which findings flow from the data can be judged.

Table 3.2

Given that most measures are part of or shape either the validity or reliability of a piece of research, the following sections will explore the encompassing concepts of internal validity, external validity and reliability in terms of this, more interpretive, study.

3.3.5. Strengthening & Judging Internal Validity

Validity is a crucial measure to any study and the absence of it can render that study worthless (Cohen et al, 2000). Its importance in research is reflected by Gall et al (2002), who list its seventeen recognised forms. Within a qualitative study, internal validity could be addressed in a number of ways. As discussed by Bazeley (2009), the link between the data source, the design of the data gathering instrument and the basis for interpretation of resultant data must be correctly established and appropriately clarified. It is arguably critical that the data gathering method be appropriate and sensitive to the type of data that are going to properly inform on the research question. This stipulation is based on the notion that the credibility of a qualitative study rests upon three main forms of validity: 'descriptive', 'interpretive' and 'theoretical' (Maxwell, 1992). The first is concerned with factual accuracy of the accounts made by the researcher, which should not be made up, selective or distorted; they should be objectively factual. The second is the ability of the researcher to catch the meaning, interpretations, terms and intentions that situations and events have for the participants in their own terms. This has been referred to as 'fidelity' (Blumenfeld-Jones, 1995); what it means to the researched person or group and has no clear positivist counterpart. The last of these is the extent to which the research findings and relationships established actually explain the phenomena under investigation. LeCompte & Preissle (1993), in Cohen et al (2000), argue that the internal validity, or credibility, of a qualitative study can be enhanced by using low-inference descriptors, multiple researchers, participant researchers, peer examination of data and mechanical means to record, store and retrieve data. Whilst all of these clearly bolster validity, judgements about the overall credibility can only be made through provision of a comprehensive, or appropriately 'thick description' by the researcher (Gall et al, 2002).

3.3.6. Strengthening & Judging External Validity

External validity, or 'transferability', is herein defined as *"the degree to which the results can be generalised to the wider population, cases, or situations."* (Cohen et al, 2000) In positivist methods, external validity forms an explicit feature of study design and statistical approaches, matched to a given sampling strategy, allow levels of probability to be ascertained for given findings with respect to a wider populous. As direct a relationship is not as readily testable with post-positivist studies, largely because of the nature of the data and an inherent tension arising from its philosophy and intensions. To exemplify this, the Ethnographic method seeks to generate a ‘thick description’ and understanding of a given phenomenon (Gall et al, 2002, and ‘good’ results are likely to illuminate subtle features of the phenomenon in question, which, whilst of interest to the study, also demonstrate it as more unique, in turn lowering the ‘external validity’ or transferability. This tension, however, is tempered somewhat by the fact that these studies take place within the native environments of the phenomena under investigation. Robson (1993), draws upon what has been termed by Aronson & Carlsmith (1986), as ‘experimental realism’ and ‘mundane realism’. The first of these argues that an experiment is seen as ‘realistic’ when the situation both involves the subjects and has an effect upon them. The latter argues that the investigative situation should reflect events as they would occur in ‘real life’. From the perspective of the pupils, their own technology classroom, and the intended content of learning, constitutes a real-life context. Within such contexts, Lincoln & Guba (1985), strongly argue that it is possible to assess the ‘typicality’ of a situation – the participants and settings, such that assessments of how these findings may translate into other settings and cultures can be made. Furthermore, they argue that it is not the responsibility of the researcher to provide an ‘index of transferability’, but rather, provide sufficiently detailed, or thick, descriptions such that readers may assess whether given instances of ‘transfer’ are possible (Cohen et al, 2000). This is commonly referred to as the ‘Ecological Validity’ and constitutes the main sub-set of external validity in qualitative research. Once again, ecological validity is judged through the use of thick descriptions within the research study and can involve a huge range of factors inclusive of, but not limited to, the Hawthorne Effect, novelty and disruption effects, interaction and temporal effects, and the effect of introducing the experimenter to the real-live context (Gall et al, 2002). Robson (1993) notes that these are often referred to as ‘demand characteristics’ and, in strengthening the aforementioned notion of a ‘typicality’, further notes that the demand characteristics within real life settings are far lower than those within controlled settings. Accounting for and describing these factors throughout the study will allow sometimes tentative judgements to be made as to the extent to which findings could be expected to apply to similar populations in similar settings.

3.3.7. Triangulation & Validity

In quantitative studies, one of the most powerful and traditional tools employed to bolster validity has been triangulation. This concept has its basis in the survey method where multiple measures would be made in an attempt to increase validity through producing corroborating evidence but has since evolved to other contexts and, latterly, is accused by some of being misused (*see* Bazeley, 2004). There are two aspects to this. The first is that by employing triangulation as it was originally understood necessarily assumes there to be a single, objective and measurable reality (Flick, 1992). In the case of studies into social phenomena, this is fundamentally challenging to accept and at odds with the philosophical basis. The second is that triangulation, in many cases, fails to address validity because each source must be understood in its own terms and this means that subsequent evidence is, by definition, unable to corroborate findings (Fielding & Fielding, 1986 *in* Bazeley, 2004).

These arguments strongly suggest that the use of the term 'triangulation' within post-positivist enquiry is, in many cases, inappropriate. Notwithstanding this, Bazeley (2004), argues that although in may not bolster validity in the technical sense, the use of multiple data gathering methods is nonetheless essential in building up depth and can prove critical in understanding the processes taking place. Brannen (2005), also accepts the issues associated with 'triangulation', but moves this argument forward by citing four recognised approaches in which results from different analyses are combined within mixed-method studies. These are defined as follows:

Elaboration or Expansion

Qualitative data analysis may exemplify how patterns based on quantitative data analysis apply in particular areas. Here, the use of one type of data analysis adds to the understanding being gained by another.

Initiation

The use of a first method sparks new hypothesis or research questions that can be pursued using a different method.

Complementarity

Qualitative and quantitative results are treated as different beasts. Each type of data analysis enhances the other. Together the data analyses from the two methods are juxtaposed to generate complementary insights that together create a bigger picture.

Contradictions

Where qualitative and quantitative findings conflict. Exploring contradictions between different types of data assumed to reflect the same phenomena may lead to an interrogation of the methods and to discounting one method in favour of another (in terms of assessments of validity or reliability).

The approach adopted by this study is one of 'complementarity', where the use of multiple data gathering streams allows a composite representation of social reality to be generated.

3.3.8. Reliability

In both quantitative and qualitative approaches, reliability is regarded as a critical component of validity and, by definition, a study cannot be valid if measures within are shown to be unreliable. Within qualitative studies, reliability is considered to be the extent to which a researcher will arrive at the same conclusions about a given phenomena when employing the same approach. Measures that increase reliability are arguably those that engender a consistency and a degree of objectivity in approach. Whether this is with regard to aspects such as coding or interpretation, it can only be judged based upon clarity of description and methodological approach.

3.3.9. The Emic Perspective, Etic Perspective & Reflexivity

Gall et al (2002), discuss the significance of both the emic and etic perspectives within qualitative studies. To understand a phenomenon from the emic perspective is to understand it from the participant's point of view, whilst understanding it from an etic perspective involves the views and constructions of the researcher as an outsider. In addressing the emic perspective, a study may employ approaches that allow understandings and views to be expressed by the participants in their own terms and, as with anthropology, employ methods such as participant-observation to do so. In addressing the etic perspective, a researcher may draw conclusions from observations or analyses related to pre-existing theory, often in terms appropriate for the academic or outside community. It is arguably the case that, as with this study, elements of both will be present in a great deal of research, but will be subjected to differing emphases.

A previously cited approach in accounting for the etic dimension of a qualitative study is 'reflexivity', which is often employed by ethnographic researchers, and increasingly by educational researchers (Gall et al, 2002, p.461). This not only draws upon a researchers intuition and judgement, but also, more explicitly, seeks to reflect upon how the researchers and the research methods influence the phenomena they are studying (Gall et al, 2002, p.503). These approaches are now recognised by many as a core feature of qualitative studies (Finlay & Gough, 2003), and provide an introspective dimension that can assist when judging validity. This approach, however, is conceptually and philosophically complex.

A paper written by Mauthner & Doucet (2003), retrospectively describes the reflexive aspects to their Doctoral research which they now consider to be very limited. They argue that a deeper reflexive understanding has only emerged through many more years of experience but which was unavailable to them at the time. This is suggestive that to 'do reflexivity' properly within this study may be somewhat aspirational and efforts to do so may be at risk of compromising the integrity of the endeavor. Lynch (2000), further supports this through arguing that although reflexivity is assumed to do something within a study that would necessarily be missed if it were not employed, the reality of *"what reflexivity does, what it threatens to expose, what it reveals and who it empowers, depends upon who does it and how they go about it."* (p.12) Given both the epistemic stance of this study, and the nature of the research question, it is both unnecessary and beyond the scope of this research to integrate reflexivity in the manner and depth found in anthropology or ethnography. The necessity to acknowledge and reflect on the researcher's role within data gathering and analysis, however, is accepted. This, in many ways, is akin to the more surface-level reflexivity established by Pollner (1991) *in* Lynch (2000), that contributes to the study's infrastructure of accountability.

3.3.10. Ethical Considerations

Given that the intended participants within this study will be school pupils, appropriate ethical considerations and measures must be put in place. Gall et al (2002), provide in-depth consideration of the ethical issues surrounding aspects such as participant selection, informed consent, privacy and confidentiality and vulnerable populations.

This research study was subjected to review and approval from the University of Glasgow, Faculty of Education Ethics Committee, and the investigation will be carried out within the parameters and measures defined within. The main steps taken include:

- Informed consent for participating pupils with the option not to participate.
- The use of a plain language statement to describe the study for the schools and participants.
- Maintaining the anonymity of all pupils involved in the research.

3.4. The Epistemic Rationale for this Study

The purpose of developing this is to define the epistemic stance and perspectives adopted for this study. This rationale is developed from the discourse in the previous sections and forms the basis of choices regarding the different approaches adopted with different elements of the study. This is regarded as essential in light of the fact that the study does not belong to a defined domain, and that, unlike quantitative studies, it is not possible to define exactly how issues of validity and reliability will be addressed at the start.

This study will:

1. Address the research question through exploration of both the processes and knowledge the pupils engage with, as well as the developing physical solution.
2. Be characteristically interpretive and post-positivist in nature.
3. Study the phenomena of interest within the real-life setting.
4. Use the conceptual framework as a basis on which to explore the phenomena but actively seek and integrate emergent findings to refine and develop understanding.
5. Employ methodological eclecticism and a variety of approaches based on their appropriateness for the purposes of the study.
6. Address rigour and establish trustworthiness in terms of credibility, transferability, dependability and confirmability by:
    a. Providing a clear description of the sampling, the design of data gathering instruments and analytical approaches and relationships to the research question.
    b. Ensuring that the path from data, through judgements toward claims of knowledge is clarified and appropriately substantiated.
    c. Providing a thick description of the ecology of the study.
    d. Accounting for and reflecting on any effects induced by demand characteristics with specific consideration of the role of the researcher.
    e. Putting measures in place to maintain and determine consistency between participating classes.

  f. Employing, as appropriate, measures and controls such as observational protocols to increase objectivity and repeatability in measurement and clearly define the terms and basis upon which judgements are made.

7. Through the use of a mixed method approach, employ complimentarity in building up a composite representation of the phenomena under investigation.
8. Account for the emic and etic perspectives in building understanding, and making claims of knowledge of, the phenomena under investigation.
9. Will employ only surface-level reflexive turns as far as is necessary and appropriate in building the study's infrastructure of accountability.
10. Will take all necessary ethical measures in accordance with the University's Code of Ethics under the advisement of the Faculty of Education Ethics Committee.

Chapter Four

Study Design & Data Gathering Methods

4. Study Design & Data Gathering Methods

Chapter 2, the Conceptual Framework, defines technological problem solving within this study and Chapter 3 defines the research question and underlying epistemology through which this is explored. This chapter describes the overall design of the study and the data gathering approaches employed in addressing the research question. This is presented in five sections, detailed as follows:

Sampling Strategy
This details the multistage sampling approach employed within this study to ensure a representative spread of demographics within a relatively small sample size.

Design of Problem Solving Task
A bridge building task is identified and developed as a suitable vehicle for comparing group differences in terms of intellectual processes and knowledge as set forth by the conceptual framework.

Design of Structures Units
A unit of work is developed allowing pupils to learn about the concepts and knowledge associated with the task and promote greater ecological validity.

Data Gathering Methods for Structures Unit
A range of data gathering instruments are developed to gauge pupil understanding and ecological validity.

Data Gathering Methods for Problem Solving Task
Here, data gathering instruments specific to the main problem solving task are developed.

4.1. Developing an Approach to Sample Identification

Cohen et al (2000), highlight the fact that the quality of a piece of research stands or falls by both the appropriateness of methodology and instrumentation as well as the suitability of the sampling strategy (p.92). This assertion is echoed by Gall et al (2002), who, in accepting it is not possible for a researcher to investigate an entire population, purport the importance of selecting a sample which is representative of the population to which they wish to generalise research findings (p.213). Indeed, Gall et al go on to highlight three common mistakes made in sampling as summarised below:

1. Investigation of persons within the appropriate population simply because they are available.
2. The selection of subjects who do not belong to an appropriate population for the intended investigation simply because they are available.
3. Biases caused by the use of experimental and control groups from different populations.

Gall et al (2002), discuss the importance of identifying an appropriate 'target population'. They also highlight the characteristics of a target population as either tending to a large group of people over a wide geographical area, or a small group of people concentrated in a single area (p.216). Furthermore, they assert that representative samples may not easily be drawn from large, broadly defined populations and that in such instances, it is necessary to develop complex methods of selecting cases from different areas, different-sized communities, and different types of schools (p.217).

In many ways, this describes the approach adopted by this investigation which falls within the realms of purposive or probability sampling rather than random, non-probability sampling (Robson 2003; Cohen et al, 2000). The process employed is described with detail and clarity such that later judgments regarding the transferability of any knowledge claims can be made. While the broad context of this study, 'Technology Education in Scottish Secondary Schools', provides a preliminary focus, it infers little more than a general descriptor for a large population. Selection of a sample within this population must be done in such a way as to ensure 'population validity' as far as possible. Gall et al (2002), draw on the work of Permut (1976), who presents four criteria against which population validity within a study may be assessed. Permut (1976) argues that studies should include:

1. A clear description of the population to which the results are to be generalised.
2. A description of the sampling procedure in enough detail that another investigator would be able to replicate the process. This should, at minimum, include the type of sample, the sample size and the geographical area.
3. The 'sampling frame', that is, the lists, indexes, or other population records from which the sample was drawn.

4. The completion rate, which is the proportion of the sample that participated as intended in all of the research procedures.

In accordance with these considerations, the following three-stage convergent framework for sampling was employed for this investigation. The 'sampling frame' as defined by Permut (1976), forms a permeating aspect of the framework and the completion rate will form an element within the results section (*see* Chapter 6). The general strategy is outlined in Figure 4.1.

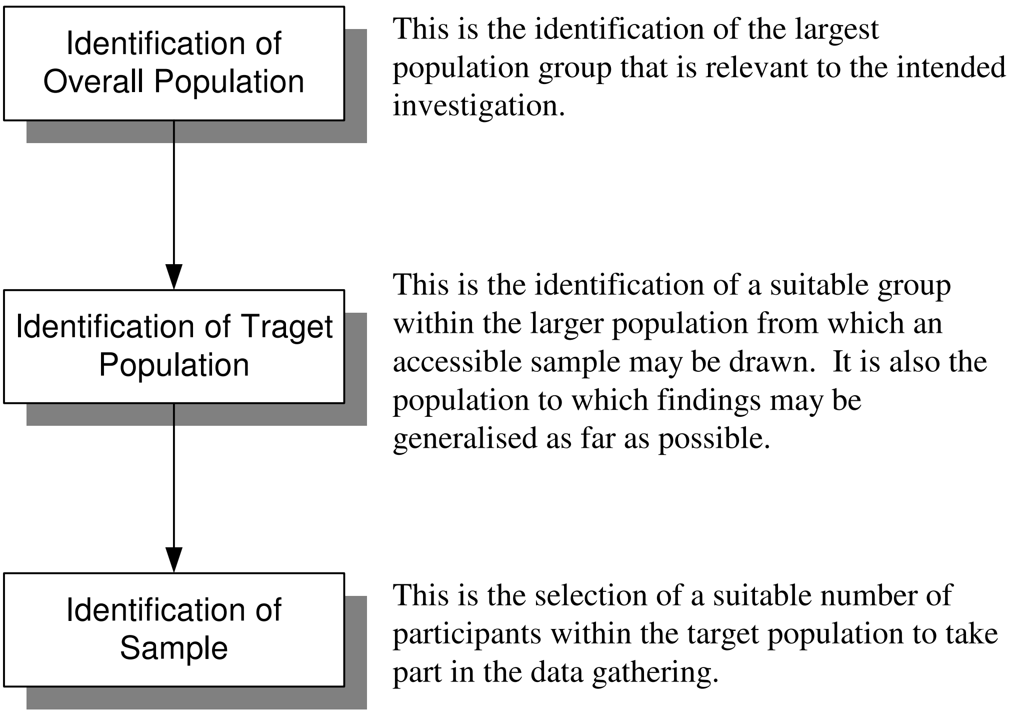


Figure 4.1 – Three-Stage Framework for Sample Selection

4.1.1. Sampling Stage 1: Identifying the Overall Population

As stated earlier, the study seeks to examine aspects of technological problem solving as it is undertaken by pupils within the Scottish secondary school education system. The most recent data derived from the 2002 school census indicate that there are 386 publicly funded secondary schools catering for a total of 316,897 pupils (Scottish Executive). Whilst it is a requirement that pupils within their first and second years of high school undertake courses in technology education, the further study of technology subjects within standard grade is optional. Whilst it was difficult and unnecessary to establish the exact number of secondary pupils undertaking each technology subject offered, Table 4.1 indicates uptake in the form of the number of pupil exams marked by the Scottish Qualifications Authority (SQA) by subject and level.

SQA Exams Marked by Subject		
Subject & Level	**Entries 2002**	**Entries 2003**
Craft & Design (Standard Grade)	15,291	15,029
Craft & Design (Intermediate 2)	780	817
Craft & Design (Higher)	2,639	2,497
Craft & Design (Advanced Higher)	71	56
Graphic Communication (Standard Grade)	9,598	9,944
Graphic Communication (Intermediate 2)	1,018	1,064
Graphic Communication (Higher)	3,016	3,087
Graphic Communication (Advanced Higher)	304	407
Technological Studies (Standard Grade)	2,659	2,244
Technological Studies (Intermediate 2)	164	200
Technological Studies (Higher)	943	997
Technological Studies (Advanced Higher)	117	133
Total Number of Pupil Exams Marked:	**36,600**	**36,475**

Table 4.1

Whilst the overall number of pupils exposed to technology subjects beyond S2 will be less than the figures above, it demonstrated that gathering data from all pupils undertaking technology was infeasible and it was hence necessary to identify a suitable target population from within this wider populous.

4.1.2. Sampling Stage 2: Identifying the Target Population

In establishing a target population, there are many considerations and criteria that could be made or applied. However, in the context of this study, three prominent considerations were made:

1. The structure of technology subjects within Scottish Secondary Schools
2. The curricular experience of pupils
3. Gender balance at different stages of secondary technology education

These are described in the following sections.

4.1.2.1. The Structure of Technology Subjects

The most common structural distinction in schools that cater for technology subjects occurs at the end of S2 as a result of the staged curricular guidelines and structures. Up until this point, secondary schools follow the 5-14 national curriculum guidelines in which the curriculum is divided into five main areas: English language, mathematics, expressive art, religious and moral education, and environmental studies. Pupils, overall, are hence presented with between 12 and 16 subjects depending upon the school and are taught, on average, by a total of 16 teachers. Technology forms one of the subjects under the environmental studies section of the 5-14 curriculum and it is not uncommon for schools to offer all pupils what is often referred to as a ‘common course’ in technology during this time.

Beyond S2, the curriculum becomes largely subject driven and, by virtue of this, more discrete in nature due to pupils’ choices regarding which subjects they undertake. At this stage, round 10% of the time available in schools is allocated to the study of scientific, social, technological, creative or aesthetic elements, and a further 20% allows student to select subjects of their own choice (Gavin, 2000 *in* Bryce & Humes, 2000). Within the technology portion, schools offer a range of technology subjects dependent upon factors such as staffing, pupil uptake, rooming and resources. Research carried out by this author indicates that, despite the vast majority of S2 pupils regarding themselves as the central decision maker regarding standard grade subject choices, these decision are affected by many, and often complex, positive and negative influences.

4.1.2.2. The Curricular Experience of Pupils

It is clear that the structure outlined previously has a direct influence upon pupils’ curricular experience in technology subjects. During S1 and S2, a given class unit has the same curricular and experiential exposure within school, whilst from S3 onward, pupils undertake a variety of subjects often different from those of their classmates.

Furthermore, the S1 and S2 technology common courses implemented through the 5-14 curricular guidelines, potentially covers all areas of technology in an introductory fashion. It is commonplace, as indicated by Gavin (2000) in respect of science, that the content of secondary school common courses are influenced to a high degree by the technology subjects offered to pupils between 14 and 18 years of age. During standard grade, higher still and advanced higher still, technology subjects are taught discreetly as Craft & Design, Technological Studies, Graphic Communication, Product Design or Practical Craft Skills (SQA). This results in subject areas that are characteristically different to each other, partly as a result of the external influences upon the subjects throughout their historical development.

Table 4.2 provides a very general analysis of the main foci of the three Standard Grade (SG) technology subjects offered within Scottish secondary schools. The exclusion of Higher Still and Advanced Higher Still in this section is because structurally, they do not present an immediate influence upon content in S1 & S2. The analysis was carried out against the modes of problem solving and using the subject aims (*see* Subject Arrangements, SQA).

Analysis of SG Subject Foci Against Established Knowledge Types and Modes		
Central Focus	**Dominant Forms of Knowledge**	**Modes of Problem Solving**
<u>Craft & Design</u> Solving practical problems through designing, making and evaluating.	Procedural Conceptual	Design Troubleshooting/Emergent Problem Solving
<u>Graphic Communication</u> Knowledge and use of techniques and procedure to effectively communicate information graphically.	Procedural	Emergent Problem Solving Design (dominated by sequential application of heuristics and methods)
<u>Technological Studies</u> Knowledge and understanding of technological concepts and systems and the application of this to solve technological problems.	Conceptual Knowledge of Principles Procedural	Design (by systems) Troubleshooting/Emergent Problem Solving

Table 4.2

From this analysis, it is clear that no two subjects are characteristically similar. Whilst Craft & Design and Technological Studies appear quite similar, the nature of the design undertaken within them and the differing emphases on knowledge types sets them apart. It can be argued that the differing aims and characteristics of the subject areas engender different problem solving approaches and educational outcomes.

4.1.2.3. The Gender Balance in Technology Subjects

It is suggested by Bain, in Bryce & Humes (2000) that technology subjects have been subject to a gender imbalance, referred to by him as a "barrier" and whilst he notes that Graphic Communication is sometimes the exception to this, and that initially, Technological Studies at standard grade was hoped to go some way towards a 'breakthrough' for this barrier, it is still dominated by Boys. Figures 4.2, 4.3 & 4.4, compiled with data from the National Statistic Office, demonstrate these assertions and more clearly show the gender balance in Graphic Communication, Craft & Design and Technological Studies at standard grade over a five-year period.

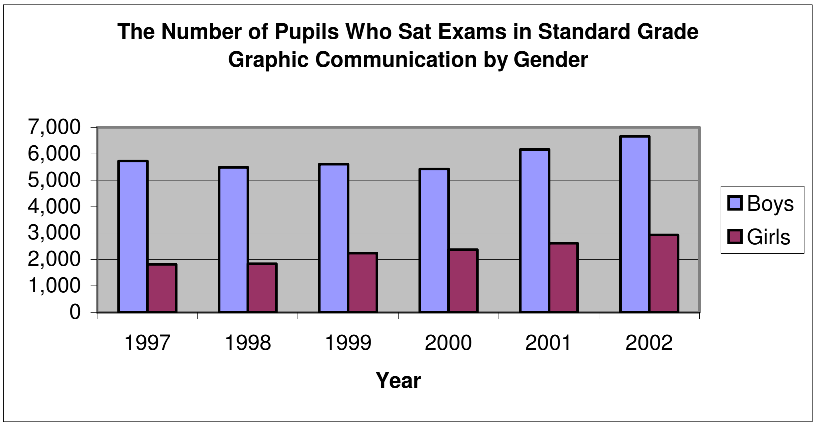


Figure 4.2

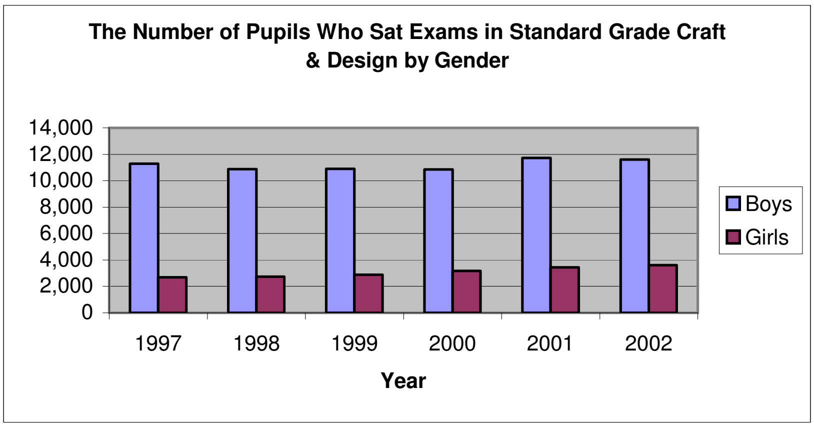


Figure 4.3

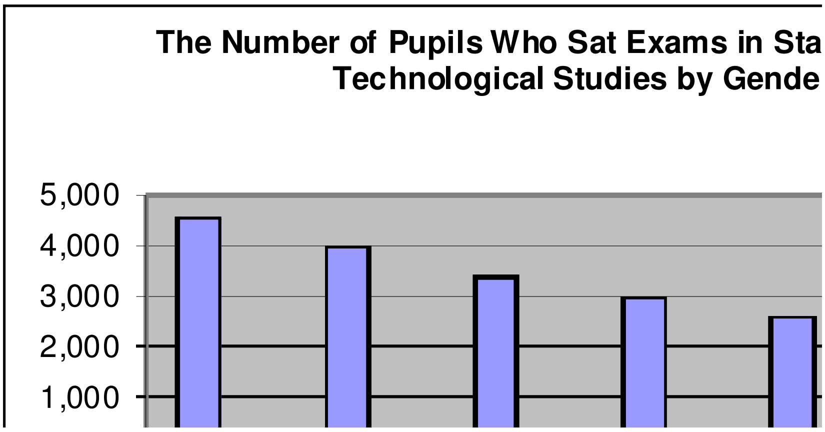


Figure 4.4

Across all subjects and years shown, the average uptake is 78% male and 22% female resulting in a very distinct gender profile from S3 onwards.

4.1.2.4. The Target Population of this Study

In considering the curricular exposure, structure, nature and gender balance for technology subjects within Scottish Secondary Schools, second year pupils were selected as the target population. The reasons behind this are stated below:

1. All pupils within a class share similar curricular exposure and experience with teachers.
2. Curricular content is not confined to a discrete and characteristically distinct area; pupils experience aspects of all three standard grade technology subjects in a limited form.
3. Technology in S1 and S2 is not optional, as it is from S3 onward. The selection, or otherwise, of technology subjects by pupils in S3/S4 results in them undergoing very different curricular experiences both within and out-with technology departments.
4. Classes within S1 and S2 present a more even balance of gender than that seen within technology subjects from S3 onward.

4.1.3. Sampling Stage 3: Identifying an Accessible Sample

In accordance with the previously defined framework, the sample represents a subset of the target population that, in turn, is a subset of the overall population. The number of participants from the target population that make up a suitable sample depends very much upon the nature of the study and of the population itself (Cohen et al, 2000). Whilst it is recognised, for example, that a researcher requires a minimum of about thirty participants if meaningful, correlational statistical analysis is employed (Cohen et al, 2000), it is also recognised that research of a more qualitative nature may involve far less, even to the point of studying a single case. Gall et al (2002), discuss the issue of appropriate sample size in qualitative research and conclude that it is "entirely a matter of judgement". However, they also draw upon the work of Patton, who argues that this judgement involves a trade-off between breadth and depth:

> *"With the same fixed resources and limited time, a researcher could study a specific set of experiences for a large number of people (seeking breadth) or a more open range of experiences for a smaller number of people (seeking depth). In-depth information from a small number of people can be very valuable, especially if the cases are information-rich. Less depth from a larger number of people can be especially helpful in exploring a phenomenon and trying to document diversity or understand variation." (in Gall et al, 2002, p.182)*

The identified target population constitutes a very large number of children with many of the 433 Scottish Secondary Schools totalling between 100 and 300 second year pupils on their rolls. As such, the method by which the sample was drawn, and the size thereof, was given close consideration. Indeed, the necessity to show that the selected sample is either representative or otherwise with respect to the target population is argued to be of great importance by Gall et al (2002). Moreover, if something other than random sampling is employed, then the measures taken must allow for legitimate generalisation to take place.

4.1.3.1. Probability & Non-Probability Sampling Strategies

Sampling strategies can be broken into two main groups: probability sampling strategies and non-probability sampling strategies (Cohen et al, 2000, p.99). In the former of these approaches, every member of the wider population has an equal chance of appearing within the sample; inclusion or exclusion is merely down to chance and this method allows findings to be easily generalised. This method is used most often in quantitative or survey style research and generalisation is relatively unproblematic. In the latter form, however, members within the wider population will be purposefully included or excluded by the researcher and generalisation is harder and requires greater consideration (Cohen et al, 2000, p.102). This style of sampling is by far the most prevalent in social science-based research, partly due to the fact that, in accordance with post-positivism, studies have to take place at a local and immediate level (Gall et al, 2002, p.170).

Despite the limitations of time, cost and logistical feasibility in including all of the target population in the sample, the nature of this study is such that it firstly seeks relative 'depth' and then 'breadth'. As previously discussed (*see* Patton *in* Gall et al, 2002), this often requires the use of a small number of participants. Furthermore, because this study falls into the post-positivist tenet of 'local and immediate study', non-probability, rather than random sampling strategies, were explored.

A total of twenty sampling techniques for non-probability purposeful sampling are provided between Cohen et al (2000) and Gall et al (2002), the most relevant of which are summarised as follows:

1. Purposive Sampling (Cohen et al, 2000)

Participants are hand-picked by the researcher to be included in the sample according to the researcher's judgement of their typicality. Argued by Cohen et al as not representative of the wider population and deliberately and unashamedly biased.

2. Stratified Purposeful Sampling (Gall et al, 2002)

Selection of several cases at defined points of variation with respect to the phenomena being studied. This provides deeper insight to the phenomena with selected cases (e.g. at average, above average and below average).

3. Homogeneous Sampling (Gall et al, 2002)

Selection of a sample of similar cases so that the group that the sample represents can be studied in depth.

4. Operational Construct Sampling (Gall et al, 2002)

Sampling based upon theoretical principles and is used to explore the real-world manifestations of theoretical constructs. Example: exploring the concrete stage of Piaget's theory in different environments - the sample must consist of participants known to be in the concrete stage of the developmental theory.

5. Criterion Sampling (Gall et al, 2002)

Involves the selection of cases that satisfy an important criterion.

Though it was recognised that aspects of approaches of 'Stratified Sampling', could be adopted, the strata that would be defined, socio-demographic, are not theoretically part of the phenomena under investigation. As such, 'Criterion Sampling' sampling was chosen as the most appropriate method.

4.1.3.2. Sampling Criteria for this Study

The criteria that were established as a basis for sample selection are given in the following list:

1. Participants should be drawn from S2 technology common course classes.
2. Participants should be representative of a broad range of socio-economic groups identifiable within the larger population (employ sampling frame).
3. Participants should represent both urban and sub-urban dimensions of the overall population as these represent the categories within which the majority of the overall population of the study can be found (employ sampling frame).
4. Participants should be drawn from publicly funded secondary schools.
5. Participants should not have made subject choice selections for standard grade courses as this will likely have an effect on their perceptions of the importance or otherwise of the curricular content.
6. Account should be taken of the attainment levels of participating schools in relation to each other and to national levels (employ sampling frame).
7. Sampling strategy should remain conducive to criterion-based non-probability.

4.1.3.3. Identification of Urban & Sub-Urban Areas

Several accessible schools in both urban and sub-urban areas were initially considered. It was also recognised that there are several ways in which urban and sub-urban may be defined, however, to alleviate any ambiguity, the decision was made to employ the Scottish Executive 6-Fold Urban Rural Classification System (2002-2003). This data is presented by Local Authority and is based upon area population. The six categories used are 'Large Urban Areas', 'Other Urban Areas', 'Accessible Small Towns', 'Remote Small Towns', 'Accessible Rural' and 'Remote Rural'. To satisfy the urban and sub-urban criteria, this study considered only LEA's (Local Education Authorities) that are overwhelmingly accounted for in the first three categories, which, between them, account for 78.5% of the Scottish Population.

With consideration of the above and the practical accessibility of sample participants, three local authorities were selected. These are shown in Table 4.3 with the Urban-Rural data for Urban and Sub-Urban areas:

Urban Rural Data by Selected Authority				
Local Authority	**Large Urban Areas**	**Other Urban**	**Accessible Small Towns**	**Other Areas**
Glasgow City	99.6%	0%	0%	0.4%
East Dunbartonshire	59.1%	26.9%	7.1%	6.8%
Falkirk	0%	85.7%	4.6%	9.6%

Table 4.3

As can be seen from the table above, Glasgow City Represents a very heavily populated, almost exclusively, urban area, East Dunbartonshire has large urban population as well as a populous from sub-urban regions whilst Falkirk is largely sub-urban with no large urban component at all. Beyond these ratings, areas generally become typically rural and remote and thus unsuitable for the purposes of this study. In accordance with sampling criterion 3, one secondary school from each of these authorities was identified. This process is described below.

4.1.3.4. Selection of Participating Schools: Academic & Social Factors

Two further sampling criteria were considered in selecting appropriate schools: that of academic attainment, and socio-economic factors. It was necessary for this study to select appropriate schools from the sampling frame and provide sufficient detail about them to allow considered ‘generalisability’. The socio-economic data for each school will henceforth be referred to as its ‘Demographic Profile’.

Academic attainment was considered in relatively general terms at two levels: that of the local authority to which the selected schools belong, and the schools performance at standard grade level due to the more immediate influence on the S2 curriculum.

It is acknowledged, however, that generating a representative picture of the social and economic status for given areas is very complex and can be done using various measures and for various purposes (Demography & Geography Statistics Team, 2002). In view of this, the decision was made to draw upon three sources of data to provide a sufficiently high level of validity for the purposes of this study and provide a relatively strong foundation on which to identify different groups. The following sources were used to build a robust demographic picture:

1. The Scottish Area Deprivation Index

A geographic multi-measure indicator of deprivation levels.

2. The Carstairs & Morris Scottish Deprivation Score (ScotDep or Carstairs Index)

An alternative geographic multi-measure indicator of deprivation levels.

3. Eligibility for Free School Meals

A Non-Geographic indicator or economic prosperity of pupils attending a given school.

Each of these is now described.

Measure 1: The Scottish Area Deprivation Index

(Demography & Geography Statistics Team, 2002)

Bartley & Blane (1994) define deprivation indices as a measure of "the proportion of households in a defined small geographical unit with a combination of circumstances indicating low living standards or a high need for services, or both." An important consideration here is the notion that because these types of ecological indicator are geographical rather than based on people themselves, it stands to reason that deprived people may live in a relatively un-deprived area and vice versa. Despite this, they have been shown to be effective at identifying concentrations of deprivation. This level of accuracy was deemed sufficient for this study given that it will be used as part of a series of measures as suggested by the Central Statistics Unit.

The official methodology employed for generating the deprivation indices was revised after criticism of the 1998 indices and those published from 2000 onward employ a different statistical model (Revising The Scottish Area Deprivation Index, Gibb et al, 1998). It is the revised indices that were examined and are discussed from this point forward, primarily as they have been shown to be more accurate and representative.

The indices are generated using are a total of 33 indicators split into 6 different domains. These domains are: income, employment, health deprivation & disability, education skills

& training, housing, geographical access to services. The indicators used within these include mortality rates, dependants, unemployment, male long-term unemployment, non-income support, council tax benefits, education participation & attainment, home insurance rating and household overcrowding. Data to build the indices are drawn from both the national census as well as other organizations such as the health board and department of transport.

Data from all the sources are combined using factor analysis and exponential transformation to give a single resultant score that allows all areas to be ranked. Prior to the revision, two scores were presented, one for an area district and one for each of the wards within that district. These were then simply presented in rank order where the lowest rank (1 out of n where n is the total number of areas) being the most deprived. Now, the data is presented by postcode area, which means that there are in the region of 900 listings for Scotland. A numeric value accompanies the ranking for each area ranging from 16.97 which is the most deprived down to 2.03 which is the least deprived. The resolution of this index allows sector level analysis but not unit level analysis. A postcode is constructed using area-district-sector-unit codes. An example of this may be DD9 4FY, where DD is the area, 9 is the district, 4 is the sector and FY is the unit.

Measure 2: The Carstairs Index

(Carstairs & Morris, 1991)

The Carstairs & Morris Scottish Deprivation Score is another indicator developed along similar lines to the Scottish Area Deprivation Index insofar as it is based upon several census-linked demographic indicators that are combined to offer a single representative composite score. Originally, the scores are then divided into seven separate categories ranging from very high to very low deprivation. However, the 2001 Carstairs Scores, employed within this study, are divided into deciles. This index correlates well with a range of health issues and is employed by the NHS in relation to care planning.

The following four un-weighted factors are combined to give a single score:

1. Overcrowding: Persons in private households living at a density of more than 1 person per room as a proportion of all persons living in private households.
2. Male Unemployment: Proportion of economically active males who are seeking work.

3. Social Class 4 or 5: Proportions of all persons in private households with head of household in social class 4 or 5.
4. No Car: Proportion of all persons living in private households with no car.

Measure 3: Eligibility for Free School Meals

This gives a fairly good indication of the economic status of the families of those children who actually attend the school. Given that it is not geographically based, the inclusion of this measure was intended to compensate to some degree for the pockets of deprivation that may not be picked up due to the effective resolution of the other two measures.

Herein, values for those pupils listed as eligible are presented in the form of a percentage for both schools and native local education authority level. An indication of national level is also given for comparative purposes.

Through analysing the socio-economic data in the above sampling frame, the following three schools were selected:

School 1: St. Mungo’s Academy (Glasgow City)
School 2: Bishopbriggs High School (East Dunbartonshire)
School 3: Falkirk High School (Falkirk)

Demographic profiles were compiled for each of these schools that aid in justifying their selection for inclusion in the study. These are shown by Figures 4.6 through 4.14 and Tables 4.4 through 4.9.

Demographic Profile of School 1

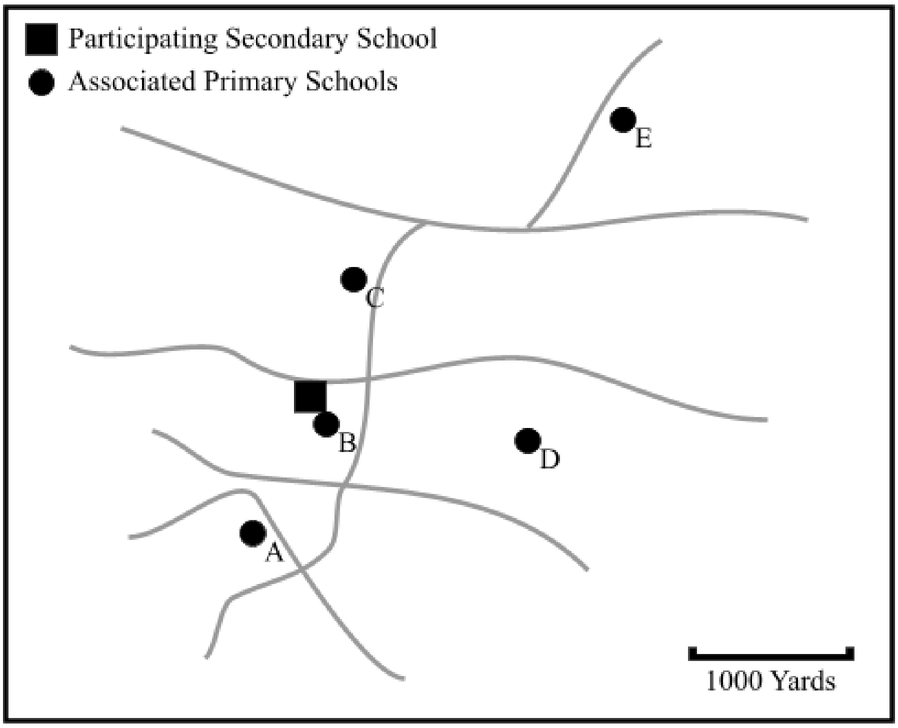


Figure 4.6 – Map of Associated Primary Schools for School 1

Schools	**SADI** (Least Deprived = 2.03, Most Deprived = 16.97)	**Carstairs Score**	**Carstairs Decile** (1^{st} = L. Deprived, 10^{th} = M. Deprived)
Participating High School	13.33	7.94	10
Primary A	15.09	13.7	10
Primary B	13.55	7.94	10
Primary C	11.23	3.99	9
Primary D	15.85	11.01	10
Primary E	10.22	3.65	9
Mean	***13.2483***	***8.04***	-
St. Dev.	***2.172***	***3.91***	-

Table 4.4 – Socio-Demographic Measures for School 1

Position on SADI (School 1):

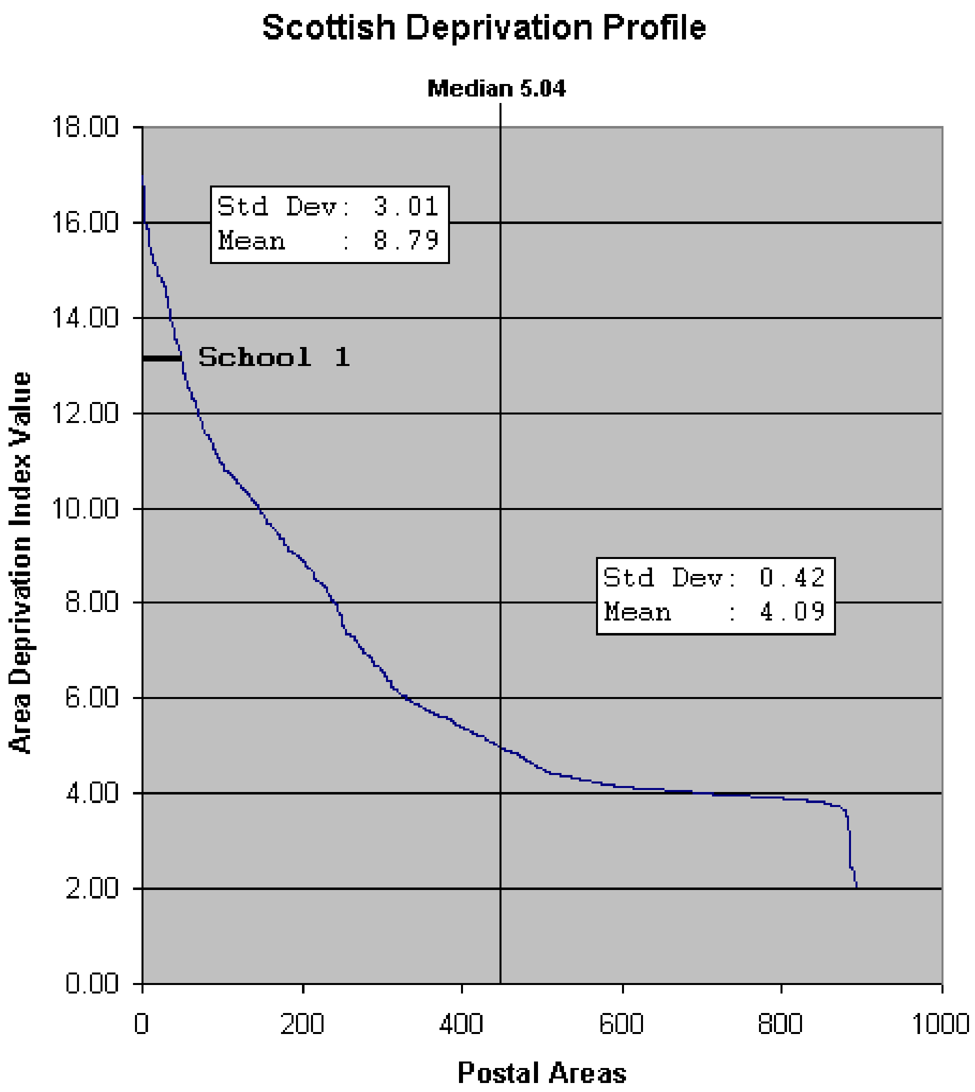


Figure 4.7 – SADI Position for School 1

	Percentage	Comparisons
Nationally	19.5%	
Native Local Authority	40.9%	Over twice national level.
School 1	47.08% (Mean)	Over twice national level.

Table 4.5 - % Free School Meal Entitlement 1999-2001 (School 1)

<u>Demographic Profile of School 2</u>

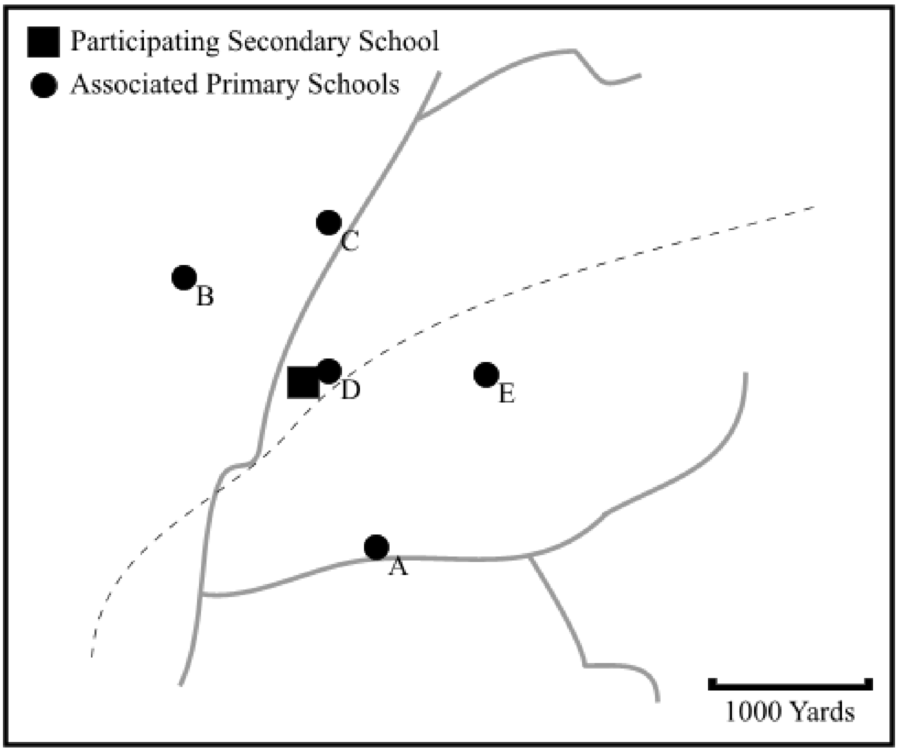


Figure 4.8 – Map of Associated Primary Schools for School 2

Schools	**SADI** (Least Deprived = 2.03, Most Deprived = 16.97)	**Carstairs Score**	**Carstairs Decile** (1st = L. Deprived, 10th = M. Deprived)
Participating High School	4.17	-3.86	2
Primary A	4.14	-1.79	4
Primary B	4.13	-4.64	1
Primary C	4.13	-4.64	1
Primary D	4.17	-3.86	2
Primary E	4.14	-1.79	4
Mean	*4.15*	*-3.43*	-
St. Dev.	*0.0168*	*1.317*	-

Table 4.6 – Socio-Demographic Measures for School 2

Position on SADI (School 2):

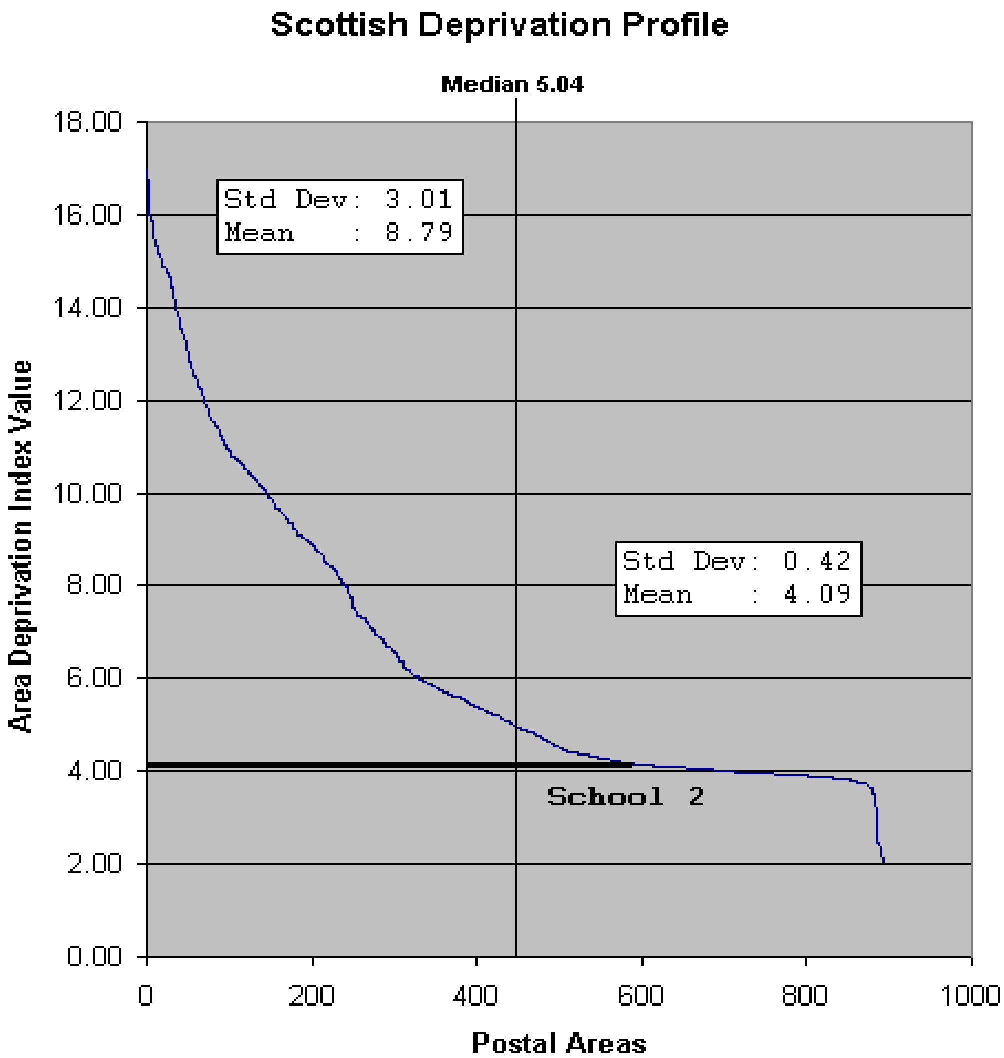


Figure 4.9 – SADI Position for School 2

	Percentage	Comparisons
Nationally	19.5%	
Native Local Authority	9.3%	Less than half the national level.
School 2	11.43% (Mean)	Approximately half the national level.

Table 4.7 - % Free School Meal Entitlement 1999-2001 (School 2)

Demographic Profile of School 3

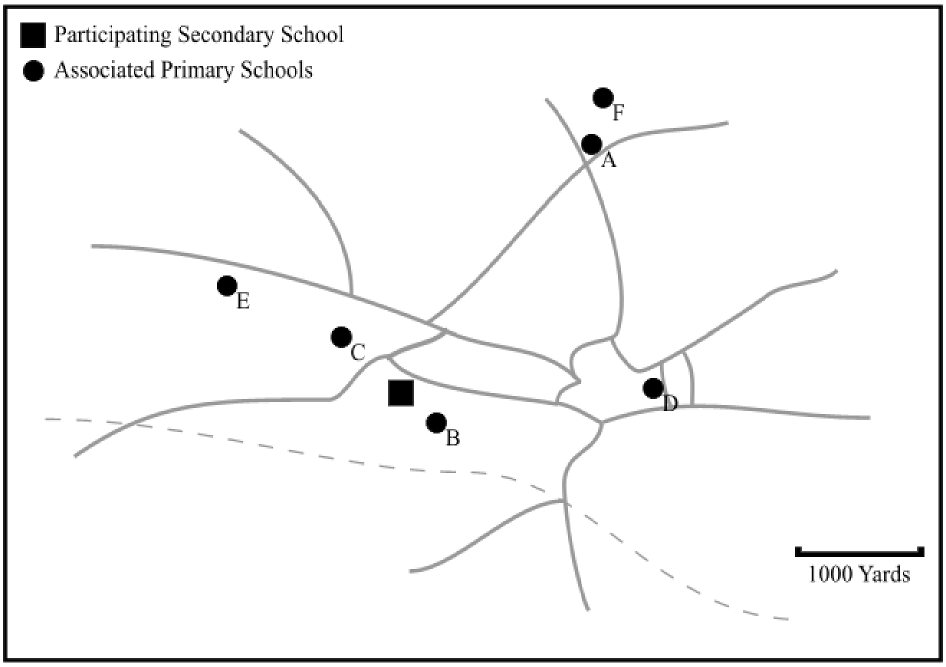


Figure 4.10 – Map of Associated Primary Schools for School 3

Schools	**SADI** (Least Deprived = 2.03, Most Deprived = 16.97)	**Carstairs Score**	**Carstairs Decile** (1^{st} = L. Deprived, 10^{th} = M. Deprived)
Participating High School	4.08	-4.05	2
Primary A	10.93	0.25	6
Primary B	4.08	-4.05	2
Primary C	10.11	2.81	8
Primary D	6.87	-0.92	5
Primary E	10.11	2.81	8
Primary F	10.93	0.25	6
Mean	*8.153*	*-0.414*	-
St. Dev.	*3.12*	*2.84*	-

Table 4.8 – Socio-Demographic Measures for School 3

Position on SADI (School 3):

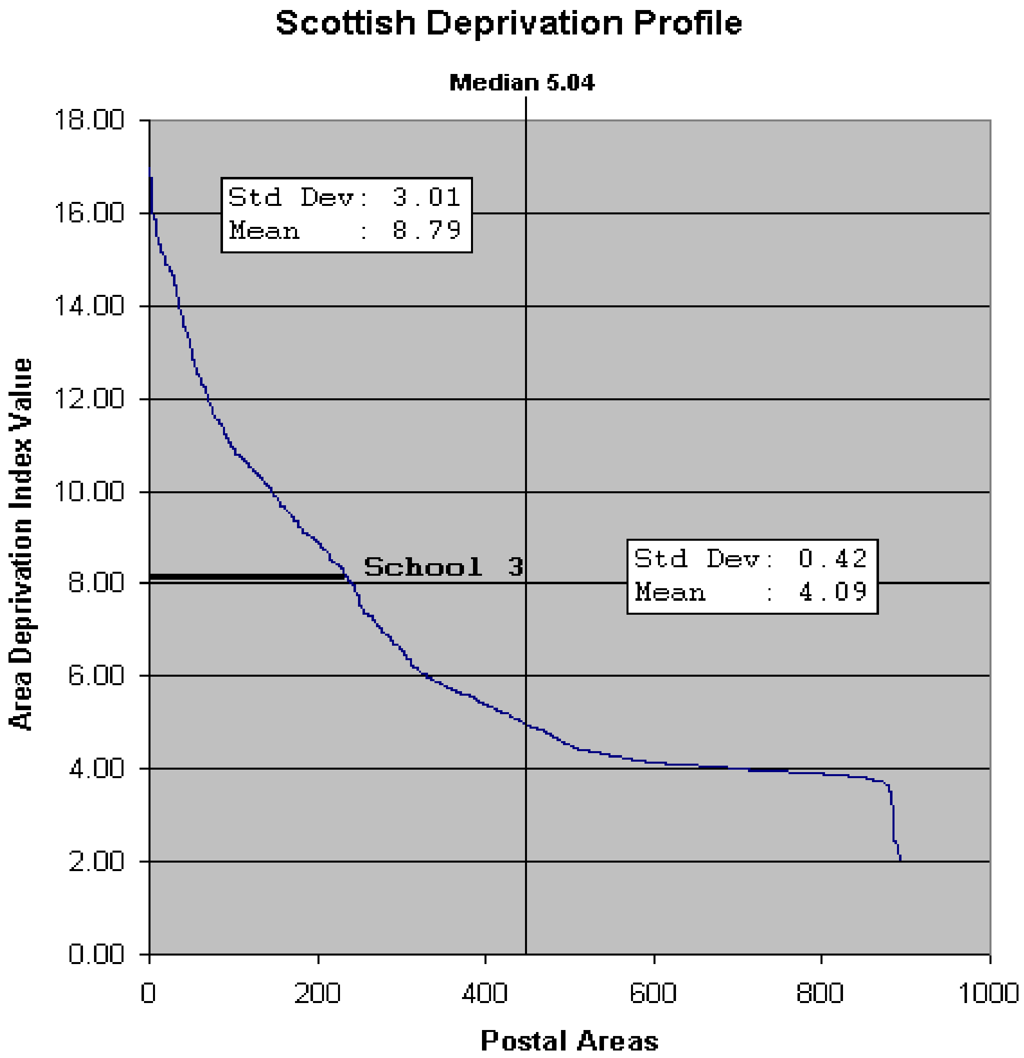


Figure 4.11 – SADI Position for School 3

	Percentage	Comparisons
Nationally	19.5%	
Native Local Authority	19.4%	Almost exactly national levels.
School 3	20.2% (Mean)	Almost exactly national levels.

Table 4.9 - % Free School Meal Entitlement 1999-2001 (School 3)

Comparison of School Profiles

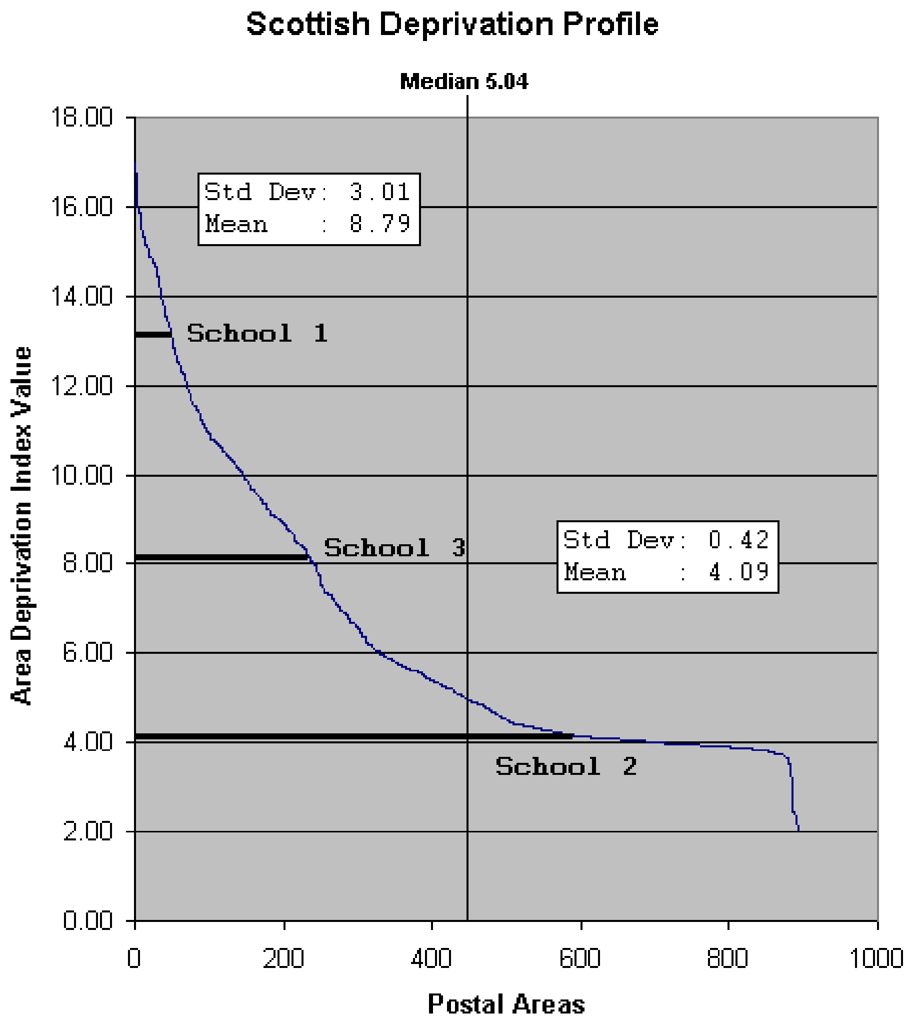


Figure 4.12 – SADI Positions for Schools 1-3

Average Decile Scores Plotted On Continuum (Mean Carstairs Scores):

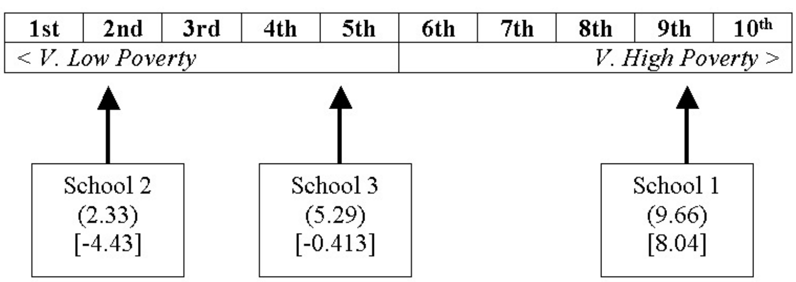


Figure 4.13 – Average Carstairs Positions for School 1-3

Comparison of Pupils Eligible for Free School Meals:

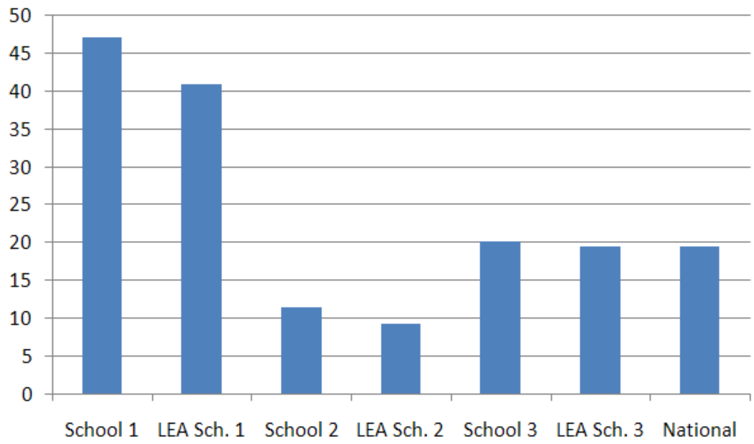


Figure 4.14 – Comparative Free School Meal Eligibility (Schools 1-3)

As can be seen from the sampling frame, these schools were selected to firstly represent urban and sub-urban areas and, secondly three strata of the socio-economic spectrum. It is also important to note the broad correlations that exist between each of the three measures employed. Both the Scottish Deprivation Index and Carstairs Scores place the schools in a very clear demographic order and position that is further backed up by the local authority figures for free school meal eligibility. In these respects, Schools selected are also largely typical of their local authorities and can be argued to be above, below and approximate to the national average respectively.

Consideration was also given to the general academic performance of the participating schools and their local authorities, which is shown in Tables 4.10 and 4.11. The data presented covers a three-year period.

General Academic Performance of Selected Authorities									
	% S4 Roll Attaining 5+ Awards at Level 5 or Better.			% S4 Roll Attaining 5+ Awards at Level 4 or Better.			% S4 Roll Attaining 5+ Awards at Level 3 or Better.		
	00	***01***	***02***	***00***	***01***	***02***	***00***	***01***	***02***
Scotland	91	91	91	77	77	76	33	34	33
Glasgow City	85	85	84	64	65	63	20	21	20
East Dunbartonshire	97	98	97	86	88	88	46	48	50
Falkirk	90	90	88	74	74	70	29	29	26

Table 4.10

General Academic Performance of Selected Schools									
	% S4 Roll Attaining 5+ Awards at Level 5 or Better.			% S4 Roll Attaining 5+ Awards at Level 4 or Better.			% S4 Roll Attaining 5+ Awards at Level 3 or Better.		
	00	***01***	***02***	***00***	***01***	***02***	***00***	***01***	***02***
St. Mungo's Academy	85	89	85	56	65	61	11	14	17
Bishopbriggs High School	96	95	94	85	84	88	36	45	41
Falkirk High School	82	82	81	63	63	59	26	23	21

Table 4.11

4.1.3.5. Description of the Selected Sample

The sample that was chosen for this study consisted of S2 pupils drawn from the three identified schools. The pupils were selected as class groups with their associated teacher to aid in preserving normality. One class was selected from each of the schools randomly and there were no additional criteria within this study that necessitated selective sampling at the level of individual pupils. A summary of the resultant sampling model for this study is shown in Figure 4.15.

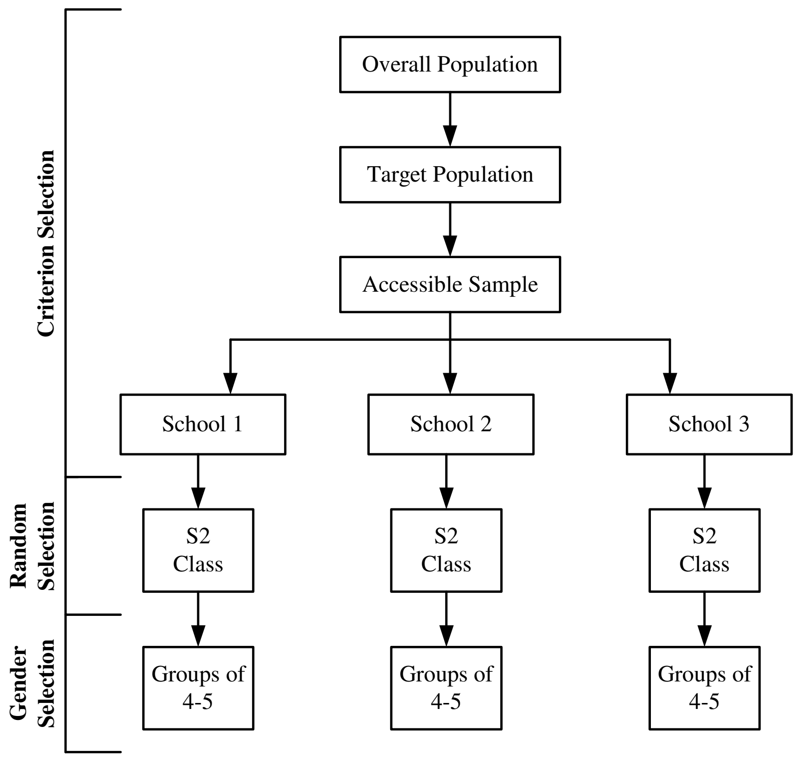


Figure 4.15 – Overall Sampling Frame Employed within this Study

4.2. Design of Problem Solving Task

This section describes the aspects considered in, and development of, the main problem solving task.

4.2.1. Composition of Pupil Groups

Research on group interaction effects and performance is both complex and extensive (e.g. Sherif et al, 1961; Harkins, 1987; Salomon & Globerson 1989, Erer et al, 1993; Rowell, 2002). Though much of this is out with the scope of this thesis to explore in detail, findings from a range of studies provide a basis on which to derive an appropriate constitution for the pupil groups in respect of gender. Howe (1997) provides an extensive review of such studies and, although it is apparent a vast number of factors affect group interaction, a number of key findings were identified as relevant to this study. Firstly, Webb (1982), concludes that boys are much more likely to respond to other boys than they are to girls in small group situations. Conwell et al, (1993), found that boys would monopolise science apparatus in small-group practical situations, with no evidence that this lessens any in gender-balanced groups. This was regarded as very significant given the necessary practical dimension to technological problem solving. Similar findings were also reported by Whyte (1984). Rennie & Parker (1987), in exploring pairs and small groups report that, in same sex pairs, girls have greater opportunity to interact than they do when part of a mixed pair. In a mixed pair, their level of active involvement tends to drop with more time spent listening and watching. In this respect, boys appear to remain unaffected by group composition. With regard to attainment, findings from research by those such as Johnson et al (1991), would suggest that attainment and interaction is maximised in small groups through co-operative learning and by mixing all grouping variables as much as possible. Whilst this may be true, pupils may need to spend several months learning how to work co-operatively, which in the context of this study, was seen to affect the transferability and is inappropriate to expect. In light of the above findings, the decision was made that single-gender groups would be used.

4.2.2. Selection of Group Members

Because the sampling criteria do not extend to the individual pupil, exactly which pupils were assigned to each group was based upon the professional judgement of the teacher. With this, as in all studies, there is a finite time in which to undertake the data gathering phase and the teacher's knowledge of the pupils was utilised pragmatically to implement groupings that had a higher chance of working well, and that necessarily avoided those that would not.

4.2.3. Designing the Problem Solving Task

Within this study, the task undertaken by participants can be considered a vehicle for the investigation of the knowledge, processes and approaches of technological problem solvers. As such, it was necessary to achieve the correct balance between the requirements of the study and the requirements of transferability. Correctly determining this balance is one means by which the study will satisfy the *emic* and *etic* perspectives defined within the rationale. From the perspectives of the participating pupils, the learning content had to be realistic, relatable and in keeping with the nature of technology curricula for this age and stage as well as providing a suitable vehicle from which to gather data that informs the research question for external audiences. With respect to the research question, conceptual framework and epistemic rationale, five criteria were established to shape the design of the main problem-solving task; each of which is discussed below.

Criteria 1: Must present a Well-Defined Problem Solving Mode

Depending upon the intellectual domain and extent to which it is defined, variation in the solutions to well-structured problems is still possible. A well-defined problem in mathematics often has a single answer, whilst a well-defined problem in technology education may still have a range of variations in the solution. In accordance with modes established in the conceptual framework, the problem was rendered 'well-defined' by including details of the outcome in the problem statement and specifying the resources available that pupils could draw upon when solving it. Unlike very open-ended tasks, pupils have knowledge of the final solution from the outset.

Criteria 2: Must Relate to the Conceptual Model of Technological Problem Solving

This was addressed in two ways. Firstly, through the initial unit of work, pupils were able to develop prior contextual knowledge of the concepts and principles related to the main problem-solving task. Secondly, the task was designed to allow for pupil activity in relation to all key areas of the conceptual model (e.g. cyclic application of conceptual knowledge, implicit/explicit procedural knowledge and knowledge of principles in moving from concept to physical solution).

Criteria 3: Must Enable Pupils to Engage in an Appropriate Range of Processes

Because Williams (2000) argues that the processes engaged with by pupils depend to a large extent upon the nature of the task, the task was designed not to be overly reliant on a single or a small group of processes but it was also recognised that it is unrealistic to expect all processes to play a role. With respect to 'small creativity' (Chapter 2), the closed nature of the task was recognised to promote functional or technical creativity over aesthetic creativity as the latter is more closely associated with more open problems. In a sense, this is not dissimilar to engineers who are sometimes seen to produce creative functional solutions within a range of practical and economic constraints.

Criteria 4: The Task Must be Challenging for, and Achievable by, S2 Pupils

Ascertaining a level of difficulty from curricular documentation is challenging as, unlike for maths and English, no national standard exists for technology in Scotland. Challenge was achieved by setting the problem within the paradigm of 'explicit problem solving' promoted by Frensch & Funke (1995) in Chapter 2. Although pupils did have prior knowledge of the solution, the task was complex to the extent that they could not readily know how a solution will be produced or what form it would ultimately take. Assuring the task is achievable was done through consultation with the participating class teachers (see 'Expert-Based Evaluation, Gall et al, 2002).

Criteria 5: The task must support 'Normality' from the Emic Perspective

As far as possible, the task was designed not to differ greatly from those found within technology departments. In line with this, the task was presented in a format with elements common to all three technology departments through provision of a brief, associated restrictions and success criteria. Furthermore, the problem related to something with which pupils are familiar and able to contextualise with existing personal knowledge. This is argued by Hennessey & Murphy (1999) to be characteristic of an 'authentic' task.

4.2.3.1. Selection of a Conceptual Content Area

In view of the above criteria, 'Structures' was selected as a compatible content area for investigation. It has associated conceptual and practical elements that naturally foster technological activity and is based upon the scientific principles of forces. Structures are often covered in technology departments during S1 and S2 and are sufficiently flexible to be tailored and pitched appropriately.

'Bridges' were selected as a sub-topic area, something with which all participants are familiar. Cantilever bridges were selected as a sub-topic for the problem-solving task for two specific reasons. Firstly, cantilevers represent a type of structure specifically designed around the discrete principle of turning moments. Secondly, the level of abstraction between the underlying principle and its physical manifestation is comparatively low and subsequently easier for pupils to comprehend than, for example, the principles associated with member redundancy or internal stress. It is one of the few areas that allow the opportunity for pupils to 'see' the effects of a principle within a physical artefact.

Figure 4.16, illustrates the fundamental components of the cantilever bridge: the cantilever arm and the intrinsic principle of turning moments.

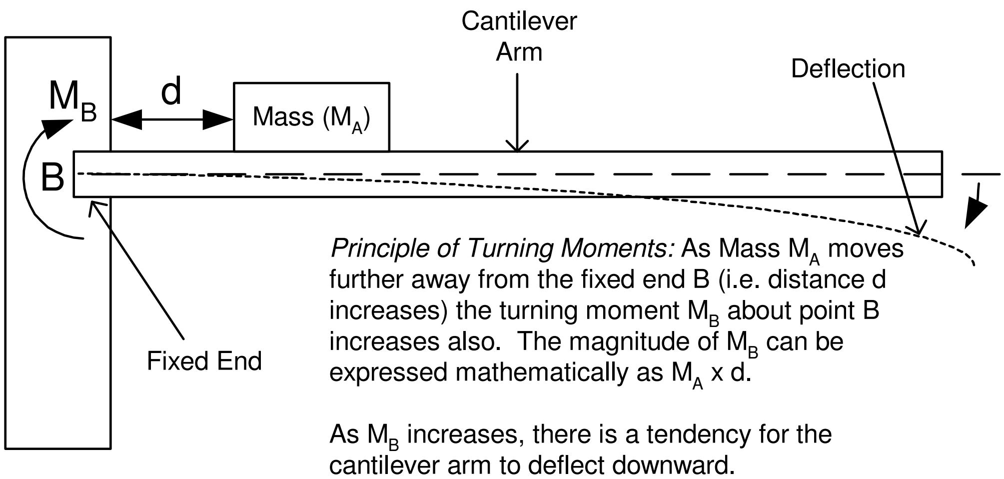


Figure 4.16 – The Cantilever Arm & the Principle of Turning Moments

4.2.3.2. Framing the Problem

Framing the problem is a process that helps define the scope and requirements of a problem along a number of strands for every participant. Within this study, the problem frame consisted of a problem statement, list of materials, list of resources, conditions and restrictions and success criteria. This is described below and forms the main source of 'task knowledge' for the pupils (*see* Chapter 2: Conceptual Framework).

The Problem Statement

"You are a team of Engineers employed by a company to design and make a model of a cantilever arm for a new bridge they plan to build. The company already has the road surface and vertical supports they want, but they need a rigid structure that will allow cars to travel safely along the cantilever."

Materials

The materials to solve the problem were carefully selected for their differing physical properties. From the participant's perspective, the materials are sufficiently limited that a range of them will be required to solve the problem but varied enough to allow for technical creativity in their solutions.

The following materials were provided to each group:

1. 6 sheets of A4 paper
2. 10 Cocktail Sticks
3. 4 strips of plastic
4. 1 sheet of A4 card
5. 4 drinking straws
6. 150cm of sewing thread

Resources

Each of the groups also required resources that allow them to join, cut and measure materials as well as work with design ideas. Groups were also issued with the following:

1. Sticky tape
2. All-purpose glue
3. A design booklet upon which they can sketch ideas and so forth
4. Two rulers
5. Two pairs of scissors
6. A length of cardboard road surface

In addition, each group was issued with a robust wooden model of the location in which the intended bridge will be built (*see* Figures 4.17 & 4.18). The model consisted of an area of water, an area of land, and an existing vertical structure. The length of road surface integrated with this structure but was not strong enough to support its own weight. Each group constructed their solution to the problem on this base.

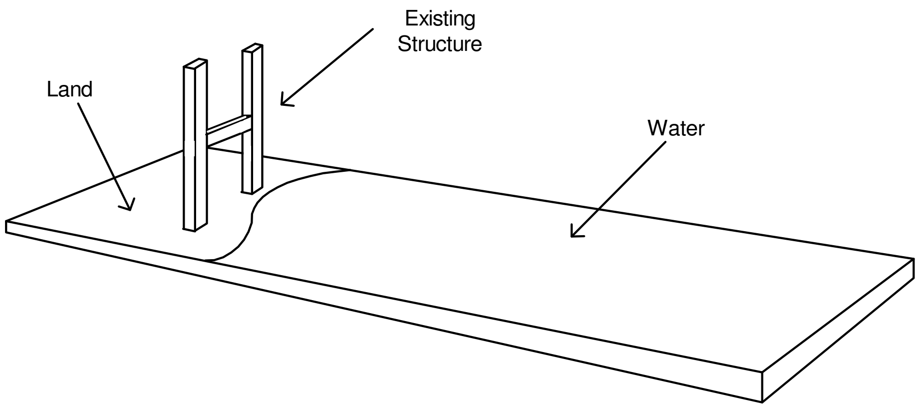


Figure 4.17 – Pictorial Representation of the Base Board

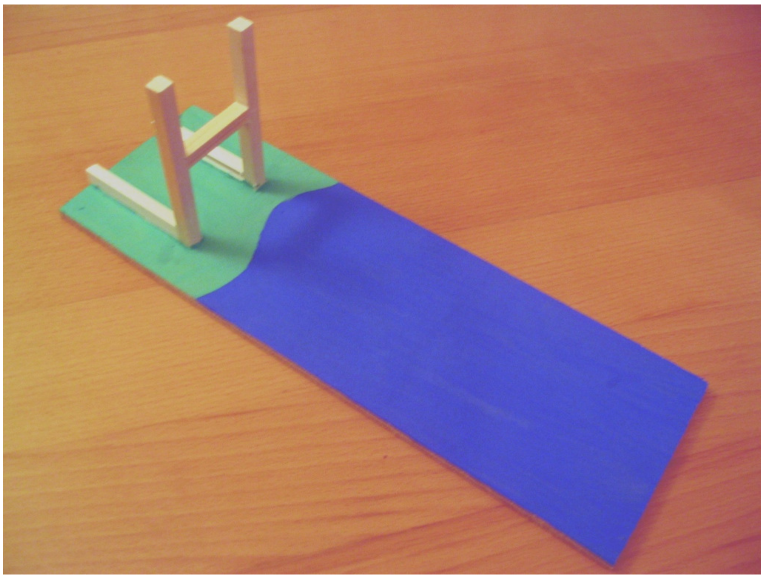


Figure 4.18 – Photograph of a Real Base Board

Conditions & Restrictions

The following conditions were also issued to pupils at the start of the main problem solving task:

1. Your groups is allocated two, forty-minute periods of time in which to completely solve the problem
2. Any design ideas must be sketched in the booklets provided
3. You can only build on the land and not the water
4. You can only use the materials and resources provided

Success Criteria

The following success criteria were also disseminated to each of the groups:

1. The road surface should be well supported along its length, and
2. The road surface should not bend when a car drives across it.

Pupils will also be told that their final solutions will be subjected to physical testing using a 250g mass.

4.2.3.3. Ecological Implications of the Problem Solving Task

Ecological factors permeate many aspects of the study. Decisions were made regarding the classroom setting, normality from the perspective of the pupil and the associated learning to be led by the classroom teacher. The design of the study, the problem solving task and the structure of the learning environment, however, were also seen to exert forces upon the ecological validity. Johnson et al (1981), identify three forms of learning endeavour that exist within classrooms: individualistic, competitive and co-operative. Each of these engenders a different type of motivation and learning dynamic. Given the aforementioned brief and that pupils will work in groups, the implication of this design is that this study explores technological problem solving in a competitive context.

4.3. Developing the Preceding Unit of Work

The preceding unit of work serves two specific functions within this study. Firstly, it furnishes pupils with knowledge of the concepts and principles that relate to the main problem-solving task and, secondly, it bolsters the consistency between participating classes, thus aiding credibility. To adequately bolster sample consistency, it was necessary to consider and account for the conceptual content, the means by which pupils and teachers engaged with this, and how understanding is determined.

This was done through the design of a common unit of work for all schools, teacher training and data gathering in the form of observations and completed pupil task sheets. The following section provides a synopsis of this approach.

4.3.1. Conceptual Content & Unit Design

The teaching unit was designed to allow pupils to explore, in a qualitative manner, the following content which was identified in relation to the proposed problem-solving task. The order shown below is based upon increasing conceptual complexity and was the order in which pupils worked through the unit.

1. Types of Bridges
2. Compressive & Tensile Forces
3. Material Selection (for Tension or Compression)
4. Strength & Rigidity (Triangulation)
5. Cantilever Arms
6. Turning Moments & Changing Magnitudes of Force

From this list of six, the three core content areas are Turning Moments, Tension & Compression and Triangulation. These are recognised to relate most directly to the cantilever problem solving task.

A teaching plan was developed to direct the unit of work on bridges, which ran for between two and three 40-50-minute periods. Pupils undertook the main problem solving task immediately following this. Although there were timetabling differences between participating schools, the time allocated during the latter problem-solving phase was intended to remain as consistent as possible between classes. The learning outcomes for the unit of work are as follows:

Pupils should be able to:

1. Name and describe the three main types of bridge
2. Explain what compression and tension mean
3. Show where they might act on a given bridge
4. Show how triangulation aids the overall strength and rigidity of a structure
5. Describe what a moment is and show how it affects a cantilever arm

A power point resource was employed to aid the delivery of these outcomes forming a balance between control over inter-class consistency and the teachers' own freedom to deliver the learning using their own professional judgement and style with which the pupils were familiar. An exemplar slide from this presentation is shown in Figure 4.19.

In addition, a range of bespoke resources were developed to aid in enhancing the delivery of the concepts and principles involved. A system developed to allow pupils to measure the deflection resulting from turning moments at different points along a cantilever is shown below in Figures 4.20 and 4.21. This was supplied to all schools as part of the unit.

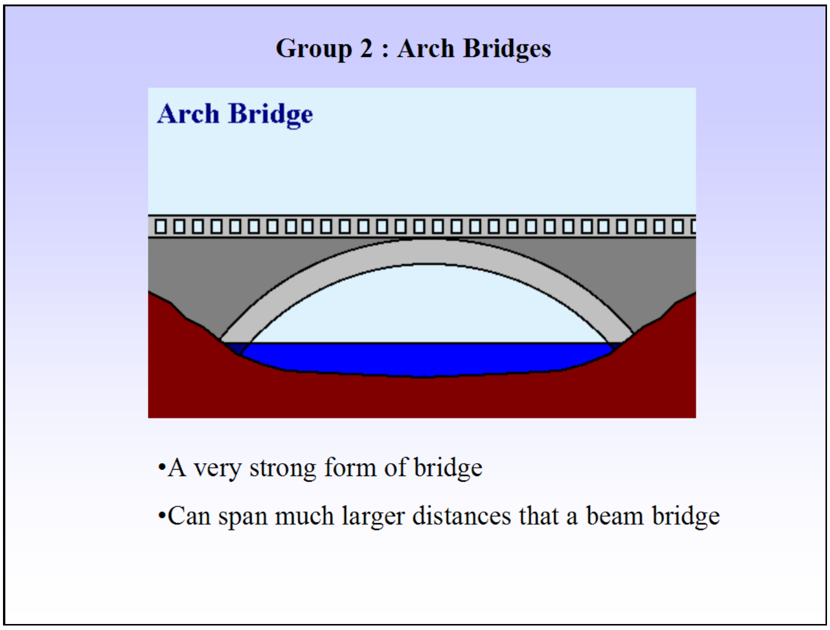


Figure 4.19 – Exemplar Slide from Structure Unit PowerPoint

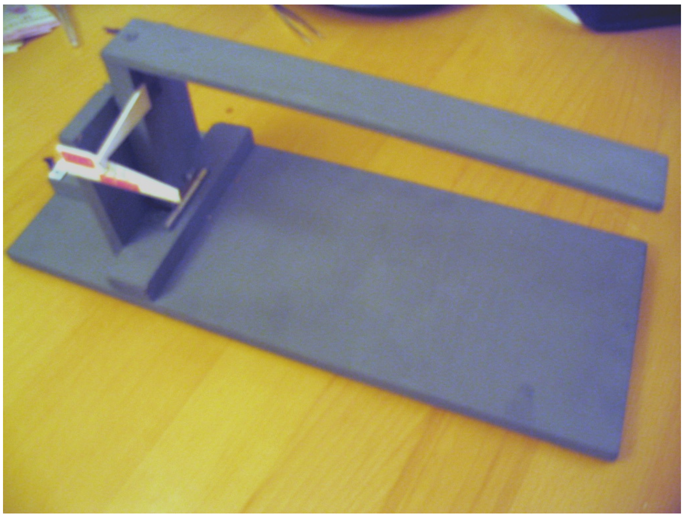


Figure 4.20 – Measuring Magnitude of Deflection (Overall)

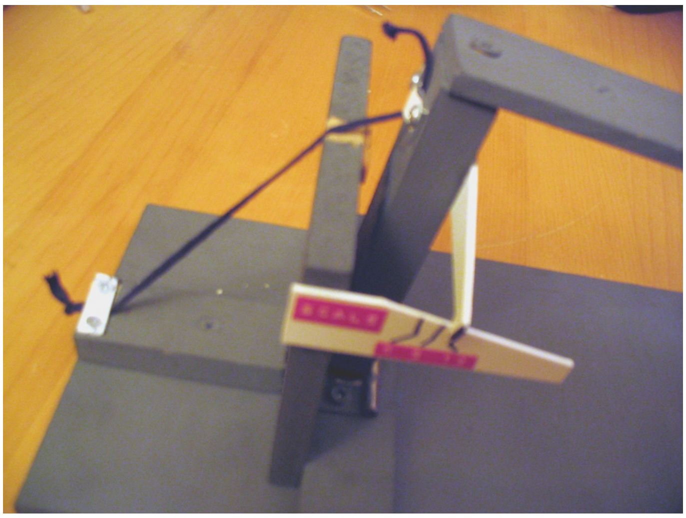


Figure 4.21– Measuring Magnitude of Deflection (Detail)

4.3.2. Teacher Training

Training for the participating classroom teachers consisted of both printed support materials and a series of face-to-face meetings in which both the wider research study and the teachers' role within was discussed. Detailed guidance was given to classroom teachers regarding such things as the content to cover and the depth thereof. It was stressed that pupils should be dealing with these in an introductory and qualitative manner with no expectation to perform calculations or ascribe numerical values to magnitudes. This guidance is shown in Appendix 1. Two thirty minute training sessions were held prior to data gathering with the provision that teachers could seek clarification or further information at any point during the study.

4.4. Data Gathering Instruments for Structures Unit

During the structures unit, five data gathering instruments were employed to build up a picture of:

1. The pupils' resulting knowledge and understanding
2. The nature of the learning, teaching and exposure to content (consistency/ecological validity)
3. The effects of the researcher within the classroom setting (study effects)

A series of task sheets was used to gauge pupils understanding at key points throughout the unit. Gall et al (2002), discuss what constitutes a good test and the five criteria for judging the overall quality: 'Objectivity', 'Standard Conditions of Administration and Scoring', 'Standards for Interpretation', 'Fairness' and 'Validity and Reliability'. These relate to such things as unbiased scoring, consistency in how pupils undertake tests, allocation of time and so forth, however, much of this does not apply here insofar as the proposed testing is not standardised. Table 4.12 shows the measures that will be taken in view of this and the finalised task sheets are shown in Appendix 2.

Measures Taken to Enhance Task Sheet Quality	
Objectivity	Task sheets will be made anonymous and marked against a bank of acceptable answers.
Standard Conditions of Administration and Scoring'	Pupils will undertake task sheets at the same points throughout the unit of work. During the training, Teachers will be given guidance how to deal with pupil questions and the amount of time that should be allocated for completion of each task sheet.
Standards for Interpretation	The results from the task sheets will be norm-referenced and considered in terms of the other classes participating in the sample.
Fairness	Efforts will be made to ensure that the design of the test is gender neutral and pitched at an appropriate level for S2 pupils.
Validity & Reliability	It is not necessary within this study to attempt to fully determine construct-based content validity, a process undertaken by trained experts. Questions will be based directly on the concepts and learning outcomes and through this alone will achieve a suitable level of content validity.

Table 4.12

4.5. Developing Data Gathering Instruments for the Main Problem Solving Task: Capturing & Representing Social Reality

It is neither possible, nor appropriate, to capture social reality in totality. Notwithstanding the inordinate complexity, what we understand to be reality is fluid and varies dependent upon the motivations, contexts, perspectives and nature of what is being studied. Each data gathering instrument is therefore more aptly characterised as a series of compromises that both pragmatically and theoretically facilitate, and can be defended in terms of, the objectives of the study.

In this study, data gathering instruments were developed to generate data from two distinct sources: (a) the pupil as an active problem solving agent, and (b) the developing technological solution as a physical embodiment of this agent's efforts. Although the study necessarily drew upon additional data sources, these are considered to be the core sources by virtue of the directness with which they inform upon the process and knowledge dimensions of the research question. From these two sources stemmed a range of associated methodological decisions, which are henceforth examined in turn.

4.5.1. The Pupil as a Data Source

In technology education research, the externalisations of learners form a rich source for understanding of knowledge and intellectual processes (*see* Hill, 1996; Mioduser & Kipperman, 2000; Twyford & Järvinen, 2000). This is expected to be similarly evident within the group setting adopted herein (*see* Blatchford et al, 2006). The most basic categorisation of externalisations is three-fold: predominantly verbal (*see* Johnson & Chung, 1999), predominantly non-verbal (*see* Alamäki, 1999) or predominantly symbolic (*see* Welch & Lim, 1999). A definition of each of these in terms of this study is given below.

Predominantly Verbal
Relates to a process or type of knowledge that is often externalised by the solver through spoken word.

Predominantly Non-Verbal
Relates to a process or type of knowledge that is often externalised by the solver through an observable physical action.

Predominantly Symbolic
Relates to a process or type of knowledge that is often externalised by the solver through written language, symbols, numbers, diagrams or sketches.

Appendix 3 details the likely forms that different phenomena will be manifest in context of this study.

Previous studies exploring this type of problem solving employ the use of video cameras in a bid to capture all three forms of externalisation at once. In this capacity, video is a tool that offers the closest we have to capturing reality in its 'totality' and allows for very detailed and considered retrospective analysis. Many of the studies cited within the conceptual framework (e.g. McCormick, 1996), employ this approach, however, logistically, they can be cumbersome and are arguably best suited to capturing the activities of a very small sample; the sample within this group will be in the region of 60 pupils. Moreover, as a relatively new technology in this capacity, there is not a great deal of research or assessment of the effects such a device has on the pupils' expectations and the classroom setting itself. Lomax & Casey (1998), present an extensive discussion on the use of video recording in social research and, in acknowledging that there is precious little research on the effects and analysis of video and video data highlight two schools of thought. The first denies existence of the camera or researcher in the social setting and the second states that the act of videoing must affect reality and introduces a subsequent distortion in its representation of reality. From this perspective, it is possibly less valid as a discrete data gathering method than it is when used in conjunction with observations and other data sources. Whilst, ultimately, Lomax & Casey argue that neither is wholly true and that videoing can be undertaken with the correct awareness and consideration, it was felt that the logistics involved in videoing large numbers of groups simultaneously within classroom settings would present too great a demand characteristic on the setting. It view of this, multiple data gathering instruments were employed constituting a compromise between the level of information necessary and the level disruption to the natural setting and overall ecological validity.

The following sections detail the instruments that were developed for capturing symbolic, verbal and non-verbal externalisations.

4.5.1.1. Capturing Symbolic Externalisations

The participants record symbolic externalisations as a function of the problem solving process through the use of paper and writing implements. These symbolic externalisations were thus generated in a form that readily facilitated analysis at a later time.

4.5.1.2. Capturing Verbal Externalisations

Verbal data within the groups forms a key source of understanding for both use of knowledge and of process and, as such, should be represented as accurately as possible. Gall et al (2002), discuss the use of audiotapes in qualitative studies when many of the occurrences to be observed vary greatly or occur in rapid succession (p.261). They also caution that these techniques require the appropriate technical expertise to be successful. Of concern here also, are the situational factors associated with introducing a tape recorder to the classroom environment. As with the use of video recording equipment, there are mixed schools of thought regarding this. Hoepfl (1997), draws on the work of Patton (1990), who argues that a tape recorder is an indispensable tool, but also on the work of Lincoln & Guba (1985), who assert that it only has a place in exceptional circumstances because of the ‘intrusiveness’ and possibility of technical failure.

Audio recorders were chosen for use in this study on the basis that they could provide a very accurate and rich representation of the verbalisation within groups and would be less obtrusive than video cameras. One tape recorder with an appropriate omni-directional microphone of suitable range was placed in the centre of each group. As the group is the unit of study, it was not necessary to isolate the vocalisations of individual pupils. The audio data from the analogue tapes was digitised immediately following each data gathering session to reduce the risk of recording over verbal data and time distortions introduced by the physical stretching of the tape through repeated use. Any effects resulting from the presence of the tape recorders was evident on the recordings themselves and recorded as part of the structured observation. It should also be acknowledged that this author has existing experience in audio engineering and digital audio editing.

4.5.1.3. Capturing Non-Verbal Externalisations

These were observed and recorded manually by the researcher through observation. LeCompte et al (1992), touches on this through citing a group of approaches under the term: "sensory narratives", and assert this to include *"accounts of verbal, visual, tactile, olfactory and gustatory observations."* (p.xv) These interpretive accounts form the crux of what are referred to as ethnographic and qualitative methodologies (LeCompte et al, 1992, p.xv). Qualitative methodologies are also broadly defined by Strauss & Corbin (1990) *in* Hoepfl (1997) as: *"any kind of research that produces findings not arrived at by means of statistical procedures or other forms of quantification."* Whilst Robson (1993), sees the observational method as one of the central approaches to this type of research (p.190), he also makes a key distinction between two extremes of the observational approach: 'participant observation', which is truly qualitative in nature, and 'structured observation' which is more quantitative in nature. According to Robson (1993), participant observation involves the researcher seeking to become some kind of member of the group under investigation. Within this somewhat humanistic approach, findings are the result of shared experiences and normally recorded in the form of narrative accounts. It is hence likely that this form of observation is more 'event driven'. Structured observation on the other hand is very much pre-defined by its use of coding schedules that focus the researchers' observations onto particular aspects of a given phenomenon (p.193).

The role of the researcher clearly plays an intrinsic part in these differing approaches (Robson, 1993, p.194). These can be differentiated based upon whether or not the researcher discloses to participants the fact that they are conducting an investigation, or conceals it. This leads Robson (1993), to characterise the roles of 'the participant as observer' and 'the complete participant' respectively (p.196). Similarly, Gall et al (2002), include the role of 'complete observer' at one extreme end of the spectrum, as well as that of 'observer-participant'. When operating as a complete observer, no interaction takes place between the researcher and the participants and a posture of detachment is maintained throughout. The role of 'observer-participant' is one of extremely minimal interaction where observation is the primary role and interaction takes place only in an indirect way (p.268). These are arguably suitable for more structured observation and, although they assume a posture of detachment, the post-positivist paradigm acknowledges that the very presence of the researcher influences constructions and perceptions of social reality for all in the observational milieu (Robson, 1993, p198; Gall et al, 2002, p.14).

4.5.1.4. The Observational Approach and Role of the Observer

Because the conceptual framework identifies, with a good degree of specificity, the main processes involved within technological problem solving, these were employed as a lens through which to explore differences between groups. As such, the observational data gathering instrument was more structured in nature and was executed within the classroom setting through the adopted role of observer-participant. Observational behaviours are defined later in this chapter.

4.5.1.5. Observation & Demand Characteristics

To ensure a suitable level of credibility, consideration had to be given to the effects or 'demand characteristics' associated with the use of the chosen observational method. Hoepfl (1997), argues that the very presence of an observer *"is likely to introduce a distortion of the natural scene which the researcher must be aware of, and work to minimize"* (p.7). To assist with this effort to minimise, Everton & Green (1986), present a list of ten important observer effects and errors as shown in Table 4.13.

The sections following Table 4.13 describe the measures that were taken in the context of this study to minimise these errors and effects.

Ten Key Observer Effects & Errors	
Type	**Description**
1. Effect of observer on the observed	Person(s) observed change their behaviour because they are aware of the observation.
2. Effect of the observer on the setting	Presence of the observer may lead to anxieties or expectations that change the climate of the observation situation.
3. Observer personal bias	Systematic errors traceable to characteristics of the observer or the observational situation.
4. Error or leniency	When using a rating scale, the observer tends to make most ratings at the favourable end of the scale.
5. Error of central tendency	When using a rating scale, the observer tends to make most ratings about the midpoint of the scale.
6. Halo effect	Observer's initial impression distorts later evaluations or judgements of the subject.
7. Observer omissions	Because the observational system includes variables that occur very rapidly or simultaneously, the observer overlooks some behaviour that should be recorded.
8. Observer drift	The tendency for observers to gradually redefine the observational variables, so that the data collected do not reflect the original categories.
9. Reliability decay	Toward end of training, observer reliability is high, but in the field, as monitoring and motivation decrease, observers become less reliable.
10. Contamination	The observer's knowledge of one aspect of a study influences his or her perception of events observed in another part of the study. Observer expectations are a common form of contamination.

Table 4.13

Effect of Observer on the Observed

Whilst provision was made on the schedule to record effects recognised by the researcher during observation, the audio recorders continuously captured evidence of verbal externalisations resulting from the researcher's presence at all points for all groups.

Effect of the Observer on the Setting

In this study, three measures were taken to attenuate and account for this. Firstly, the participants were fully informed as to the role of the researcher, the observations, and the purposes for which data would be used. They were also made aware that this data would not be disclosed to anyone other than the researcher. This does not remove expectations but was intended to go some way towards attenuating them. Secondly, pupils were directly questioned as to whether they felt they should answer questions differently because the researcher was present. This was also discussed with the teacher after each lesson.

Thirdly, the study deliberately exploited temporal acclimatisation. The role of observer participant was adopted during both the Structured Unit and the main problem solving task to allow time for pupils to naturally become accustomed to the process and allow any initial significant effects to normalise somewhat prior to the main structured observation (*see* Measor & Woods *in* Walform, 1991).

Observer Personal Bias

The identification of specific concepts and relationships, especially with regard to procedural activity, in the conceptual framework gave a basis for the structure of the observational schedule which is specifically employed to minimise this. Moreover, using multiple data gathering instruments to inform on those phenomena of interest provides sufficient detail to allow readers to 'audit' the findings themselves (Gall et al, 2002, p.274).

Errors of Leniency& Central Tendency

This study does not utilise ratings scales completed by the researcher.

The Halo Effect

Again, the structured nature of the observation is intended to suppress this where possible. Given that the research question seeks to compare those groups that do well and those that do poorly at the problem solving task, and that these groups can only be identified after the observation has taken place, there is a risk that what was observed during the activity could bias the researcher's judgement as to what constitutes good and poor during later analytical stages. In addressing this risk, the study deliberately employs a separate modified Delphi technique (*see* Chapter 5) as a mechanism to detach the researcher from decisions as to what constitutes 'good' and 'poor' in this context. In addition to minimising distortion, it is understood that this, along with the absence of a hypothesis, helps also to reduce the risk of contamination effects.

Observer Omissions

It is recognised that no humanly executed observation can claim to be entirely free from omissions. In minimising these, however, two detailed pilot studies were undertaken (discussed below and found in Appendices 4 & 5) to refine the design of the structured observational schedule and specifically develop the researchers' familiarity and experience in using it. This, in conjunction with the frequency of observations (*see* Development of

Structured Observational Instrument, below), affords a level of sufficiency in recording the data that allowed a suitably comprehensive representation of behaviours to be developed.

Observer Drift

Prior to undertaking each structured observational session, the observational categories, codes and behaviours were reviewed. In addition, the time taken between each of the observational sessions was minimised throughout.

Reliability Decay

Once more, this is a factor that will always occur to some extent within a study. Whilst in some senses it can be a function of the importance the observer attaches to what they are doing (Gall et al, 2002, p.266), it is also closely related to observer drift. Throughout the data gathering phases, efforts are made to maintain motivation in addition to those measures taken with regard to observer drift.

4.5.1.6. The Development of a Structured Observational Instrument

The decision was made to use the Flander's System of Interaction Analysis as a basis from which to develop the structured observational schedule (*see* Amidon & Powell, 1970). Originally, this system was developed to analyse the frequency and nature of the verbal interactions that took place between the class teacher and the class. Herein, it is adapted to facilitate recording the procedural interaction between the pupil group and the developing technological solution. Although the matrix aspect of the original analysis system was not employed, the broad notion that at set intervals, 3 seconds in the case of interaction analysis, the nature of the interaction between these two variables could be quantitively recorded.

The broad characteristics of the Flanders system are listed below (*see* Amidon & Powell, 1970):

1. Analyses the nature of the interaction between the teacher and the class
2. This is done by assigning an observed interaction to one of ten possible categories. Examples of these categories include (1) accepting pupil's feeling, (2) praising or encouraging (3) asking questions and so forth. The last category is used for silence or confusion.

3. Observers are trained to use this observation system and note each interaction as it occurs. If it persists, the number denoting that category is noted every three seconds until the interaction ends.
4. The data is analysed using a matrix.

The observational approach outlined here allows for the interaction between the group and the developing solution to be recorded at regular intervals against time. Given that most of the explicit knowledge can either be inferred from the developing solution or will be verbalised by pupils, the categories for this instrument are restricted to the relevant identified intellectual processes from the conceptual framework.

Due to the potentially demanding nature of this observational approach, the method was trailed, evaluated and developed through two pilot studies, which can be found in Appendix 4 and 5 respectively. The findings from these studies are summarised below:

Pilot Study 1 (Appendix 4)
'Initial Trial of Structured Observational Instrument Using a Single Subject'

Synopsis of Pilot Study 1
This initial pilot study aimed to evaluate the use of a structured observational schedule, based on the Flanders' System of Interaction Analysis. The instrument was evaluated in terms of overall use, the 3-second duration between each observation, the format and schedule for recording data, situational factors and the identification of any apparent threats to validity. Here, validity constitutes the extent to which the instrument and the use thereof allows observable behaviours to be accurately recorded. The study took place in a small craft class of four boys who were working individually. From this group, one 12-year-old boy was selected at random as the participant. He was constructing a wooden car and after analysing the stage he was at, two observational phases were undertaken. The first was unstructured and used to define the observational categories applicable to this task. In total, 11 behaviours were identified. The second phase employed the structured observational tool over a 20-minute period. The group teacher maintained the role they would under normal circumstances and the researcher adopted the role of observer-participant.

Conclusions & Recommendations from Pilot Study 1

Overall, the pilot study indicated that the observational tool was potentially demanding but viable with the ability to produce a detailed and informative data set. The specific recommendations from this study were:

1. The duration between each observation should remain three seconds.
2. The observational instrument initially allowed only one code to be entered for observed behaviours and this should be amended to allow for more.
3. The harder the tool is to use by the researcher, the higher the threat to its validity. As such, very clear definitions of the behaviours constituting each observational category must be developed and the researcher must be very familiar with these.
4. The observational categories and subsequent codes were noted at the top of the schedule used. In future, these should be ordered according to those predicted for a given task. Where possible, this would mean that those most likely to be seen first would be listed at the start.
5. The observational instrument should be augmented so that account can be taken of any situational factors that occur during the task.

Pilot Study 2 (Appendix 5)

'Secondary Trial of Structured Observational Instrument Using Two Subjects'

Synopsis of Pilot Study 2

This study was carried out to re-evaluate the observational instrument after the aforementioned amendments were applied as a result of pilot study 1. This time, the observational instrument was used to observe a dyad of two boys engaging in a technological task. The boys were 9 years old and 11 years old. The instrument was evaluated against the same criteria used within the first pilot study to account for ease of use, sampling interval, format and recording of data and situational factors. The study again took place in a small craft class where pupils were designing and constructing modes of transport. In this instance, the two boys were embarking on the construction of a model aeroplane out of wood. Again, there were two observational stages employed. As the nature of the task was not dissimilar to that in the first case study, the observational codes were retained and an initial unstructured observational period served to augment these with any additional behaviours specific to the task at hand. A second structured observational session then took place to evaluate the revised schedule. The group teacher maintained the role they would under normal circumstances and the researcher adopted the role of observer-participant.

Conclusions & Recommendations from Pilot Study 2

This study supported the use of the tool and demonstrated that it was feasible in use with more than one participant. The tool was still able to provide a detailed and informative data set. The recommendations from this study were:

1. The time interval for making observations should remain three seconds.
2. The observational schedule used should record behaviours from top to bottom and, where possible, have the codes printed at the top.
3. The use of a timer helps regulate pace during the first few minutes of observation.
4. Time at 3-second intervals should be printed on the observational schedule.
5. The researcher must ensure that behaviours are well-defined and that codes are very familiar prior to the observation taking place.
6. Researcher should be aware that increasing the number of pupils in a group would potentially increase the number of simultaneous observable behaviours.

Comments on Pilot Study Contamination

Whilst the possibility for contamination between the pilot studies and main study is extremely slim because the behaviours being observed are so different, there were instances where expectations were unintentionally set-up in the trials. One of the recommendations from pilot study 1 was that behaviours be listed in the order most likely to be seen during the observational session. Originally, the reasoning behind this was to ease the demand on the researcher, but the decision was made to remove this amendment from the final study, as there is a risk that pre-empting behaviours so explicitly could contaminate the main observational sessions. As such, observational codes will be listed in no particular order.

4.5.1.7. Observational Codes & Behaviour Descriptors for the Main Study

Table 4.14 lists the observational categories that were developed for the main study and describes the behaviours that qualified for each during observation. These were determined through reference to the intellectual processes in the conceptual framework and consideration of the nature of the problem-solving task. Some of the behaviours listed below will have verbal components; however, they are defined below in terms of their non-verbal aspects.

Observational Codes & Associated Pupil Behaviours	
Observational Category	**Description of Behaviour/Cue**
Analysing (1)	Qualitative examination of materials, components or parts of the developing solution to determine properties or function. Can also be done conceptually through sketching.
Generating Ideas (2)	Pupils make suggestions in terms of the developing solution, materials or components prior to or during the practical phase.
Sketching (3)	Pupil(s) sketch ideas, record or write information on paper.
Discussion (discrete) (4)	Discussion that is not accompanied by any other observable process.
Modifying (conceptual) (5)	The pupil(s) alters an element of an existing idea on paper (or verbally).
Predicting (6)	Pupil makes a prediction about the global solution or part of the solution. This may be in terms of things such as performance or whether or not something will work.
Modelling (7)	The pupil(s), using sketches, components or their hands, recreates part of, or an idea for, a part of the developing solution often based on function.
Constructing (8)	Pupil(s) combines parts and components, to develop a practical solution (central process within the practical phase).
Modifying (practical) (9)	Pupil(s) alters an existing part of the practical solution.
Experimenting (10)	Pupil(s) trial an idea to determine an outcome they do not readily know. This could be to determine if they think something is worth applying to the developing solution.
Testing (11)	Application of external force by pupil(s) to make a judgement as to how well the global solution, or given part thereof, performs.
Measuring (12)	Pupil(s), using a ruler or another form of visual reference, determines a length or size of interest.
Interacting with Teacher (13)	Pupil(s), in progressing through the solution, interact with the teacher.
Group Idle or Off-Task (14)	No pupils in the group currently engaged in activity that is related to or progresses the solution to the given problem.

Table 4.14

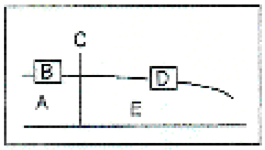
The other intellectual processes identified within the conceptual framework, due to a large verbal component or the fact that they can be considered over-arching processes, were accounted for through other data gathering streams.

4.5.1.8. Final Observational Schedule

The final observational schedule is shown in Figure 4.22.

Analysing	1	Constructing	8
Generating Ideas	2	Modifying (Practical)	9
Sketching	3	Experimenting	10
Discussion (Dismiss)	4	Testing	11
Modifying (Conceptual)	5	Measuring	12
Predicting	6	Interacting (Teacher)	13
Modelling	7	Group Idle	14

ID Code:



Artefact Map

T	I.P.	MAP	S	MEMO
57.03				
57.06				
57.09				
57.12				
57.15				
57.18				
57.21				
57.24				
57.27				
57.3				
57.33				
57.36				
57.39				
57.42				
57.45				
57.48				
57.51				
57.54				
57.57				
58				
58.03				
58.06				
58.09				
58.12				
58.15				
58.18				
58.21				
58.24				
58.27				
58.3				

- 39 -

Figure 4.22 – Final Structured Observational Schedule

In the final schedule, codes were printed at the top of every page along with an artefact map indicating which part of the model pupils are working on while being observed. Time intervals were printed with sufficient space for situational factors to be noted. In accordance with timetabling of participating schools, the schedules were designed to cover a 40-minute activity period.

4.5.2. The Developing Solution as a Data Source

Given that the developing solution is not subjected to frequent and rapid changes in the way that intellectual processes are, it was deemed sufficient to detail such changes at junctures throughout the task. The solution was therefore photographed at regular intervals using a digital camera. After each problem solving session, the models were also videoed around a 360^{o} path providing further detail that was drawn upon as necessary to aid the analysis. The approaches that were developed for analysing this data are discussed in Chapter 5.

4.5.3. Capturing the Reflexive Account

After each observational session, a verbal reflexive account was taken noting any significant observer affects, incidents or anomalies that could be used to inform on the data analysis. This was always done within 30 minutes or so of each session and recorded on a Dictaphone. To support this data, the class teacher completed a questionnaire (Appendix 6) focusing on any affects or differences they observed that could have been attributed to the study or the presence of the researcher.

4.5.4. Overall Structure & System of Data Gathering

For a given class, each data gathering session ran throughout the duration of each lesson. The pupils were given two lessons in which to complete the task thus providing two data gathering sessions per class (henceforth referred to as Session 1 and Session 2). Prior to the data gathering sessions, each class took part in a series of lessons relating to the task. Groups were single gender and, as far as possible, had four members. Groups were identified by letter and seated around suitably sized desks in the centre of which was the audio recorder. The researcher worked from the observational schedule and rotated for set durations between groups throughout the problem solving sessions. As a result, groups were observed for approximately four minutes after which the researcher photographed each model in the class (which took around 20 seconds) and then moved to the next group. This process was repeated until the end of the session and adjustments in time were made where necessary to ensure that each group was directly observed at least twice per session. After the session each of the models was videoed, the questionnaires were issued to the teacher and the reflexive account was recorded. Pupils completed summative questionnaires (Appendix 7 & Appendix 8) upon completion of the task solution after the second session. This whole process is illustrated in Figure 4.23 for any given class in the study.

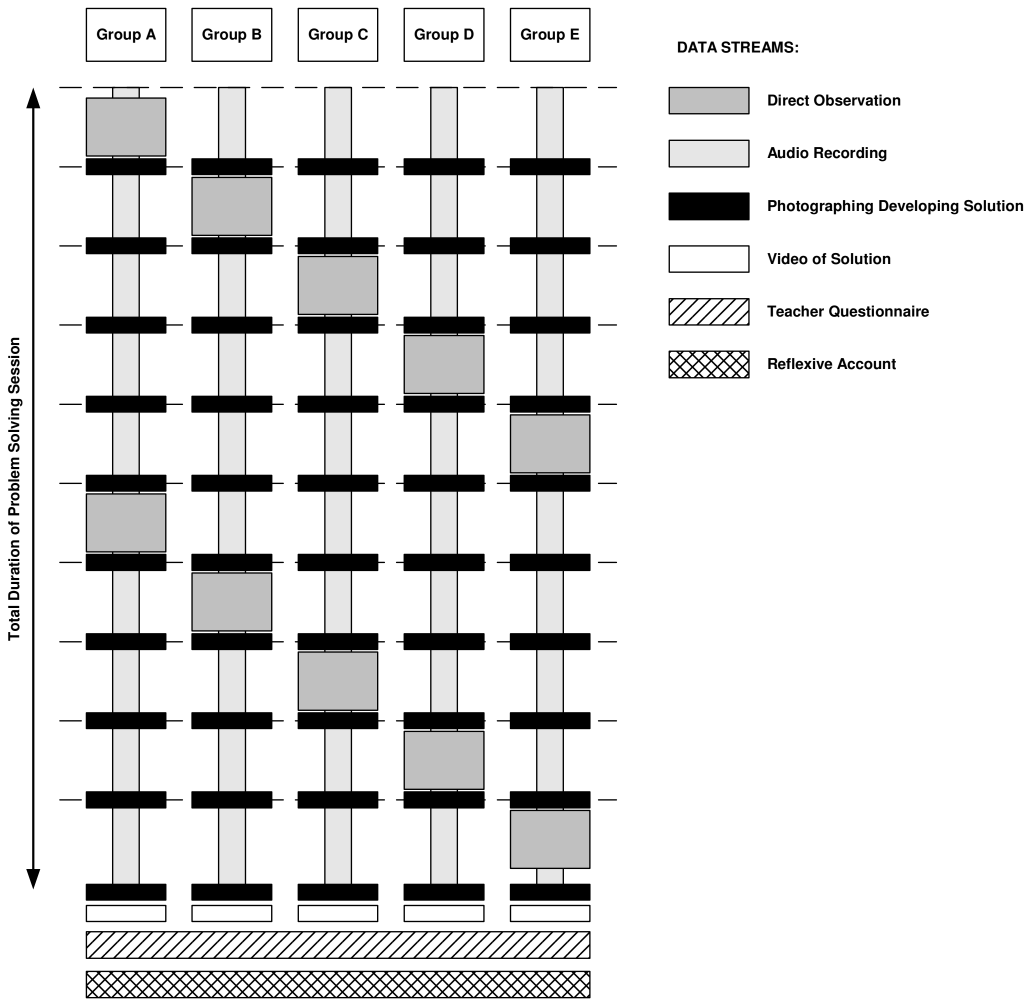


Figure 4.23 – Overall Structure of Data Gathering System

Chapter Five

Analytical Methods

5. Analytical Methods

The previous chapter describes the general design of the study and the data gathering approaches that are employed to inform on the unit of work and ultimately on the problem solving activity of pupil groups. This chapter describes the analytical approaches developed following data collection and prior to the core analysis and presentation of results in Chapter 6. This chapter is included because the nature of the data that was gathered and the hybrid design of this study, necessitated consideration of the type of analysis, the development of bespoke analytical approaches, and the modification of existing methods.

This chapter is presented in three sections:

Analytical Approach and Grounded Theory
The approach taken within the analysis comprises a significant inductive element, characteristic of some of the approaches within Grounded Theory. This section sets the approaches of this study in the context of grounded theory paradigms.

Analysis of Photographic Data
The photographs taken are for the purposes of tracking the physical development of the groups' solutions throughout the duration of the problem solving task. As such, a bespoke method is developed allowing these to be accurately represented, mapped and described over time.

Identification of Best and Poorest Solutions
In response to the risks associated with the Halo Effect and Contamination discussed in the last Chapter, and the complex and varied nature of the practical solutions, a Modified Delphi Technique is developed and administered, with supporting data sources, to identify the best and poorest performing cohorts from within the sample. The groups identified from this form the basis of the main comparative analysis in Chapter 6.

5.1. Analytical Approach & Grounded Theory

Chapters 3 and 4 describe the 'hybrid' or 'mixed method' approach employed by this study which extends to both data gathering and analysis. The core analytical strategy used to explore intellectual processes and knowledge through pupils' verbalisation is largely inductive in nature and consequently shares similarities with the Grounded Theory Method (Glaser & Strauss, 1967). Though the range of approaches within this study mean that it does not wholly subscribe to the grounded theory approach, it is necessary to locate the inductive analytical element within the context of this qualitative research paradigm.

Charmaz (2003), describes the birth of 'Grounded Theory' with the publication of 'The Discovery of Grounded Theory' (Glaser & Strauss, 1967). It is described as a set of inductive approaches to collecting and analysing data in which evolving analytical interpretations reshape the on-going theoretical analyses. It is within this process that findings and ultimately theory are seen to emerge. However, from this inception, grounded theory and its constituent strategies, developed and evolved. McCallin (2003), provides an account of the divergence that took place in the course of this evolution from which stemmed two characteristically different strains of Grounded Theory. McCallin cites Charmaz (2000) who describes the 'emergence' vs. 'sensitisation' approaches of Glaser, and of Strauss & Corbin respectively. Though both sharing the inductive angle, each constitutes a different direction within the field of grounded theory and would arguably result in quite different forms of study.

As described by McCallin (2003), the 'emergence model' developed by Glaser (1992) can be seen as a purer strain of the emergent component of inductive analysis. Herein, Glaser argues that the collection and analysis of data should take place without forcing previously prepared questions or theories upon it and that literature reviews, for example, should not be done; findings should be situated within literature only after they have emerged. This approach is wholly concerned with theory building and is arguable challenging to execute. By contrast, the 'sensitisation model' proposed by Strauss & Corbin (*see also* Strauss & Corbin, 1994), is concerned with sensitising the researcher to the specific techniques required to bolster the validity and reliability of data (often referred to as 'theoretical sensitivity'). These collectively promote greater theoretical verification. They argue that literature reviews are useful in formulating questions and establishing some of the concepts to be investigated though stress that the researcher cannot know which, if any, will have the same emphasis after collection and analysis. It should also be noted that Grounded Theory employs the same types of data gathering techniques as found in other branches of social science (Strauss & Corbin, 1994) and, irrespective of being emergent or sensitising in nature, constitute a way of dealing with and exploring data.

The aforementioned paradigms of grounded theory are seen, in many ways, to sit in opposition to each other. This, of itself, forms one of several criticisms that have been levelled at the approach (see Kelle, 2007; Cutcliffe, 2000 and Moghaddam, 2006 for discussion of this and other critiques); however, this study is seen to bear closer affiliation with the sensitisation model. The conceptual framework explores the concepts and related theory which underpin the research question. The very nature of the conceptual model and research question necessitate an inductive approach insofar as it cannot be known which intellectual processes and knowledge types are significant for task performance. Moreover, as argued by Strauss & Corbin (1994), and as evidenced in Chapter 6, the emergence of more salient concepts through the inductive approach provide an emphasis which could not previously have been determined.

5.2. Analysis of Photographic Data

Historically, there has not been a great deal of consideration of methods of analysing visual and photographic data within the social sciences. Indeed, Harrison (2002), suggests that, amongst other things, this is partly because as visual technology has developed, people have become increasingly interested in the social and political affects rather than its potential as a tool. It can now be seen that visual analysis is becoming a more mainstream method within social science and there are a variety of subsequent approaches to exploring visual data. Whilst these could be considered in-depth, Harrison, offers an opening distinction, analogous in many ways to the exploration of solving problems in or through technology found in the conceptual framework. She states that the visual data could itself be the subject of study, or, it could be a means to allow the study of the subject of that visual data. In the former instance, a photograph by the photographer William Eggleston may be the subject of study in terms of such things as its composition. However, in the latter, a photograph of a volcano erupting may give researchers evidence as to the pressures, temperatures or category of eruption. Furthermore, it can be argued that it is the orientation and purpose of the study, rather than the image itself, that determine which side of this otherwise fluid distinction a piece of visual data may fall; the same photograph could be used legitimately under both paradigms depending on the questions being asked of it. Whilst research into areas such as artwork and advertising provide examples of the visual as the subject of study (Harrison, 2002), it is the latter form that is employed within this study.

Gall et al (2002), refer to this visual data as 'communication media' and advocate approaches for analysing it in both qualitative and quantitative research (p.278). In the latter instance, they cite the fact that, for many qualitative researchers, the meanings within communication media is something that can change over time and is often unique to the individual viewing it. In this study, photographic and video data was collected to illustrate the progressive modification of a tangible inanimate solution by pupils during problem solving. This underlying rationale suggests that the level of variation in interpretation would be substantially lower in comparison to an analysis of such things as facial expressions or abstract art. If the scope of this data included such aspects as the perceived motivation of pupils and included people within the photographs, then the level of variation in interpretation could be significantly greater and may require to be treated differently from an analytical perspective. Indeed, the use of video data in the collection and analysis phase is discussed in detail by Lomax & Casey (1998), who employ it to explore midwifery consultations. Despite existing concerns within research regarding 'contamination effects', they encourage the use of video data where suitable. However, many of the issues they consider in arriving at this conclusion do not apply within this study as the video data did not include, nor was collected in the same environment as, the participants.

As such, this analysis procedure will deal with the photographic data in a quantitative manner. Gall et al (2002), advocate a structured procedure for such content analysis as shown below:

1. Specify research questions, hypothesis or objectives
2. Select a sample of documents to analyse
3. Develop a category-coding procedure
4. Conduct the content analysis
5. Interpret the results

Because this data set represents one of several employed within the study, it is not carried out as a discrete content analysis study would be. The following sections describe stages three and four of the above process as they were employed within this study for a photographic series from one group.

5.2.1. Overview of Photographic Data

The photographic data was collected at between three and five minute intervals during each session for every group in a class. The duration between each of the photographs was necessarily dependent upon the length of the lesson and the number of groups in a class. At the point where data was collected, all groups were photographed within 20 seconds.

Each photograph will henceforth be referred to as a ‘sample’ and groups, on average, have between six and nine samples describing the development of their solution during each session. A sample will hence provide data regarding the changes in the developing solution over the time period between the chosen sample and that which precedes it.

The video data provided a visual panoramic record of the stage each solution was at after each session had finished. This data was gathered to provide, only where necessary, additional information that could be used to confirm and qualify interpretations made of the photographic data. This further bolsters the validity of codes assigned during the photo analysis.

5.2.2. Scope & Limits of Photographic Data

As pupils embark on the problem-solving task, the dynamic is one of fluctuating interaction between both different pupils and between pupils and the physical solution as shown in Figure 5.1.

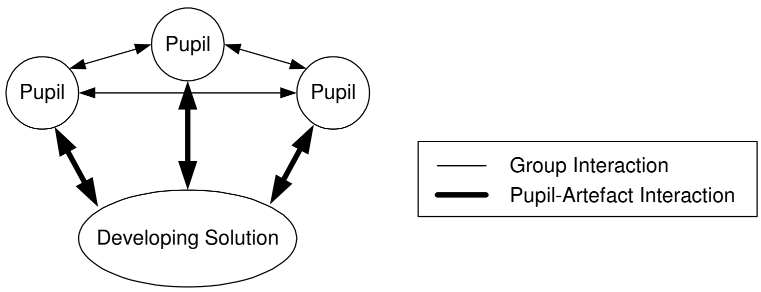


Figure 5.1 – Model of Interaction during Solution Development

As the photographs record only the solution as a manifestation of intellectual decisions and knowledge at given points in time, there is a limit or boundary around aspects on which they can legitimately inform. This defines the scope of the data. In this study, visual data was limited to the interaction between the pupil and the developing solution as shown in Figure 5.2.

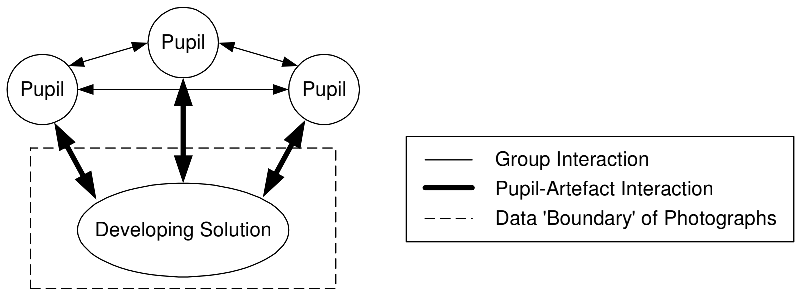


Figure 5.2 – Data Boundary during Solution Development

The same scope and limits were applied to the structured observation.

5.2.3. Coding & Photographic Data

In a sense, the coding scheme translates raw data into a form suitable for analytical operations, which in this case is quantitative and non-parametric. The nature and credibility of evidence resulting from this can only be judged if the characteristics of the transitional element are properly established. Gall et al (2002), discuss developing suitable codes for classification of content, however, it is insufficient to assume that simply applying these will provide robust evidence. Hence, the associated rules for applying codes, that they also discuss, are of paramount importance in ensuring consistency and reliability.

5.2.4. Photographic Data – Additive & Subtractive Coding

As previously shown, the scope of the data was limited to the interaction between the pupil and the solution; however, this activity can be viewed from two different perspectives. To exemplify this, identifiable blocks of activity could be conceptualised as a series of discrete events, or, as stages within the more global, developing solution. This is significant when the nature of the activity is scrutinised. If a pupil adds a component to the developing solution, as a discrete event, it can be seen as an *additive* action. This also holds true for the global development of the solution. If a pupil removes part of the existing solution, as a discrete event, this could be seen as *subtractive*, however, in terms of the globally developing solution, this is not necessarily so. The removal of a given part could have rectified a misconception and moved the pupil further through the problem space, in which sense it could actually be seen as *additive*, albeit with a conceptual change of direction. Thus, the distinction is between codes that describe the changing physicality of the solution and codes that describe the pupils' continual modification of the solution over time. In the latter case, pupils are still exhibiting a high level of interaction with the model even though its overall physicality may lessen as a result.

This is illustrated using three fictitious samples shown Figure 5.3. For the purposes of illustration, each development, 'a', will be given a value of 1.

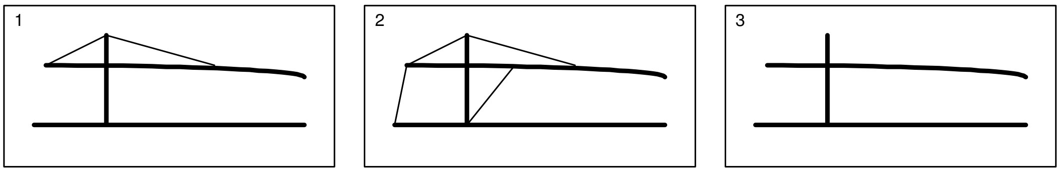


Figure 5.3 – Fictitious Practical Developments of a Given Solution

Case 1: Coding for the Changing Physicality of the Model

Pupils have added two bits of thread in the positions shown.	Additional thread is added at the rear of the bridge and a support is fixed underneath.	All existing materials are removed from the bridge.
Value = 2	*Value = 2*	*Value = - 4*

Case 2: Coding for Pupil Activity

Pupils have added two bits of thread in the positions shown.	Additional thread is added at the rear of the bridge and a support is fixed underneath.	All existing materials are removed from the bridge.
Value = 2	*Value = 2*	*Value = 4*

From this, it is clear that coding the solution in terms of pupil's activity is cumulative whilst coding for the physicality of the solution is not. Although both were included in the analytical approach, primacy was given to the physical development of the solution, as pupil activity was more pragmatically accounted for by other data streams.

5.2.5. The Identification of Coding Themes

It was decided to restrict the coding system to four aspects of interest. It was felt that these were sufficient in accounting for the way in which groups' solutions developed. They are as follows:

1. The area of the solution in which a development has taken place.
2. The materials involved in the development.
3. The degree of functional advantage offered by developments.
4. Whether or not developments were for aesthetic purposes.

The approaches developed for each of these are described as follows.

5.2.5.1. Areas of Development

Here, the development areas used were those developed for the observational schedules and described within the methodology chapter. This allows for the corroboration of data sources. This approach split the overall artefact into five possible areas, henceforth referred to as 'zones', for development as shown in Figure 5.4 and Table 5.1.

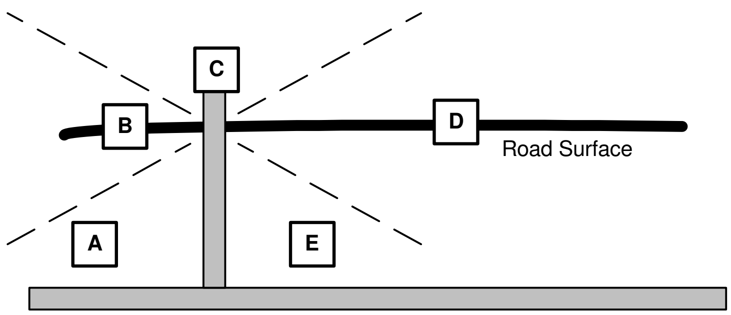


Figure 5.4 – Zones of Development Mapped onto the Existing Structure

Descriptions of Development Zones	
Zone	**Included Developments**
A	All lower and ground level to the rear of the uprights of the existing structure.
B	All elevated developments to the rear of the uprights of the existing structure.
C	All developments on the uprights of the existing structure.
D	All elevated developments to front of the uprights of the existing structure.
E	All lower and ground level developments up to the ground perimeter in front of the existing structure.

Table 5.1

This system allows for coding of discrete developments, confined to one zone, to be carried out straightforwardly with a single code such as 'B'. However, in instances where the development spans more than one zone, dual or triple codes are employed such as 'AB' or 'ABC', to represent that development. The zone system outlined will be referred to throughout the analysis for various measures and discussions.

5.2.5.2. Development Materials

Here, codes were developed to directly account for the materials chosen by pupils from those made available. These include thread, straws, paper, card, plastic strips and cocktail sticks. Glue and tape were also included to allow the joining methods to be mapped as well. The existing structure and road surface upon which groups developed their solution was not included.

It is important to note that, rather than accounting for every individual component, single 'developments' were defined in terms of the material used, and then mapped to the Zone in which it was located. The following examples illustrate the application of zone codes to material-based developments using photographs of a developing solution.

Example 1: Developments in a Single Zone

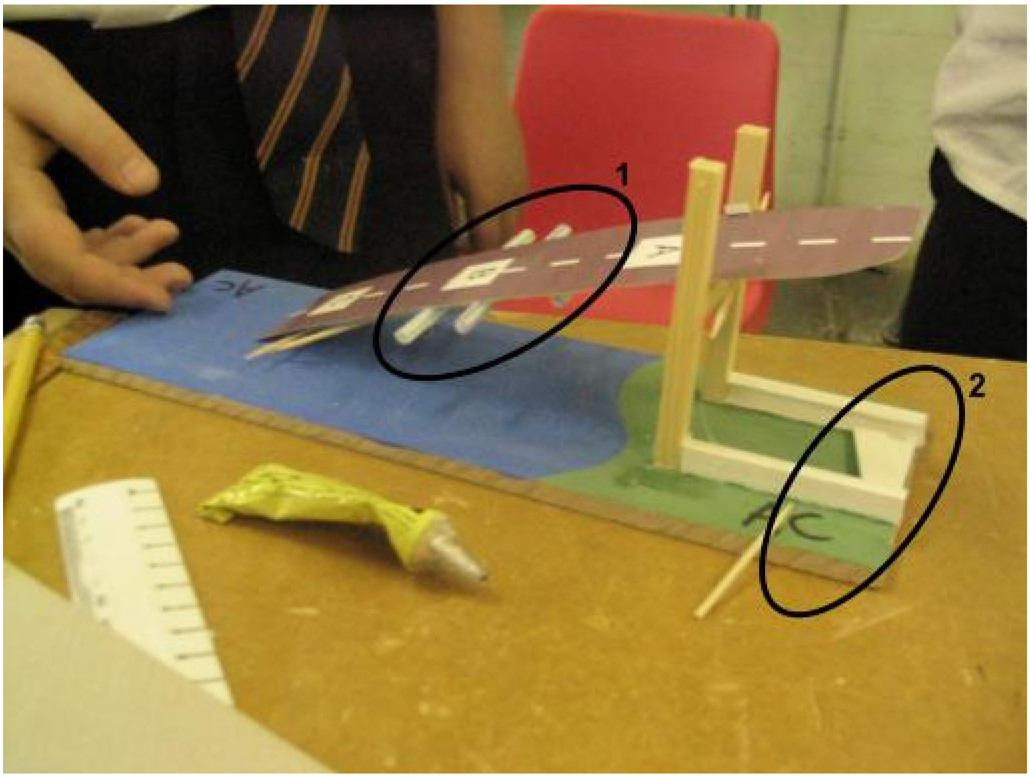


Figure 5.5 – Discrete Developments in Single Zones

Figure 5.5 shows two discrete regions where practical development has taken place in a single zone. Region 1 is coded to represent a development using Straws in Zone D, and region 2 for Plastic Strips in Zone A. In both instances, the addition (or removal) of the chosen material is the development, not the individual parts.

Example 2: Developments Crossing Two Zones

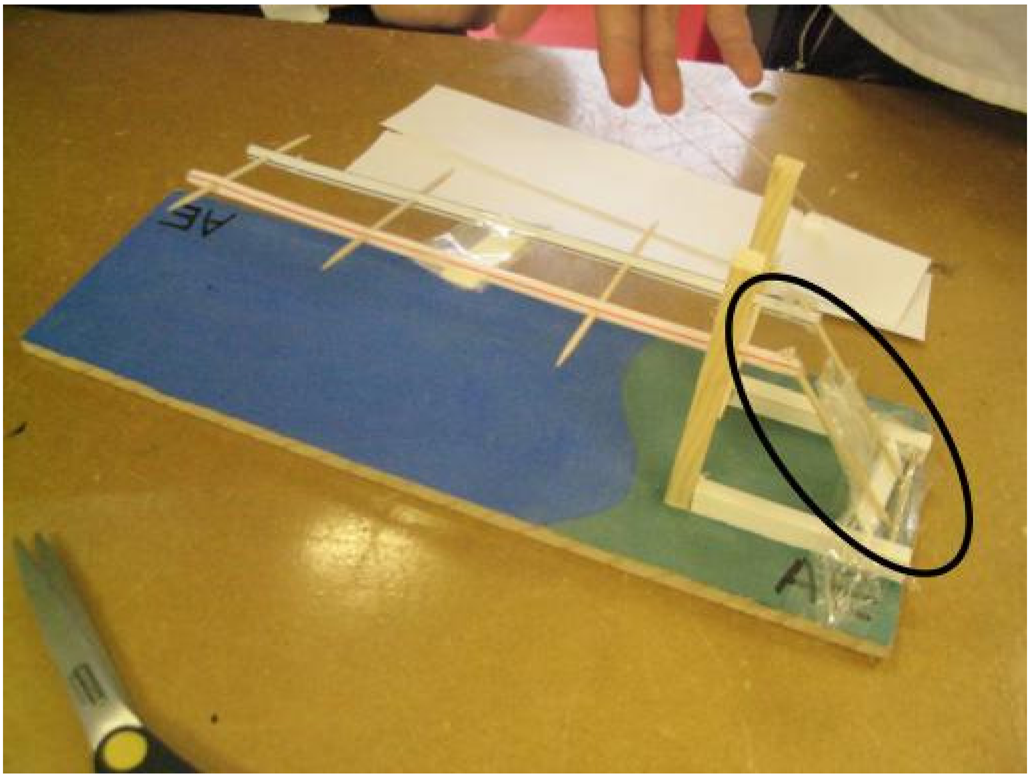


Figure 5.6 – A Given Development Crossing Two Zones

Figure 5.6 shows a more complex example of practical developments. Assuming that the parts circled represent those that are different from the last photograph, there are three new developments, because there are three materials involved: cocktail sticks, plastic strips and tape. Two of these developments (the cocktail sticks and tape) span two zones (A & B), whilst the plastic strip resides only in Zone B. As such, the following developments are identified:

Development 1: Tape (Zones A & B)
Development 2: Cocktail Sticks (Zones A & B)
Development 3: Plastic Strip (Zone B)

Example 3: A Development Crossing Three Zones

For the purposes of this example, the addition of the thread in Figure 5.7 is taken to constitute the single, new development. Four regions have been highlighted, each of which represent the developments existence within a different zone of the artefact. Of significance here is that there is no functional link between the thread and the road surface in region 3.

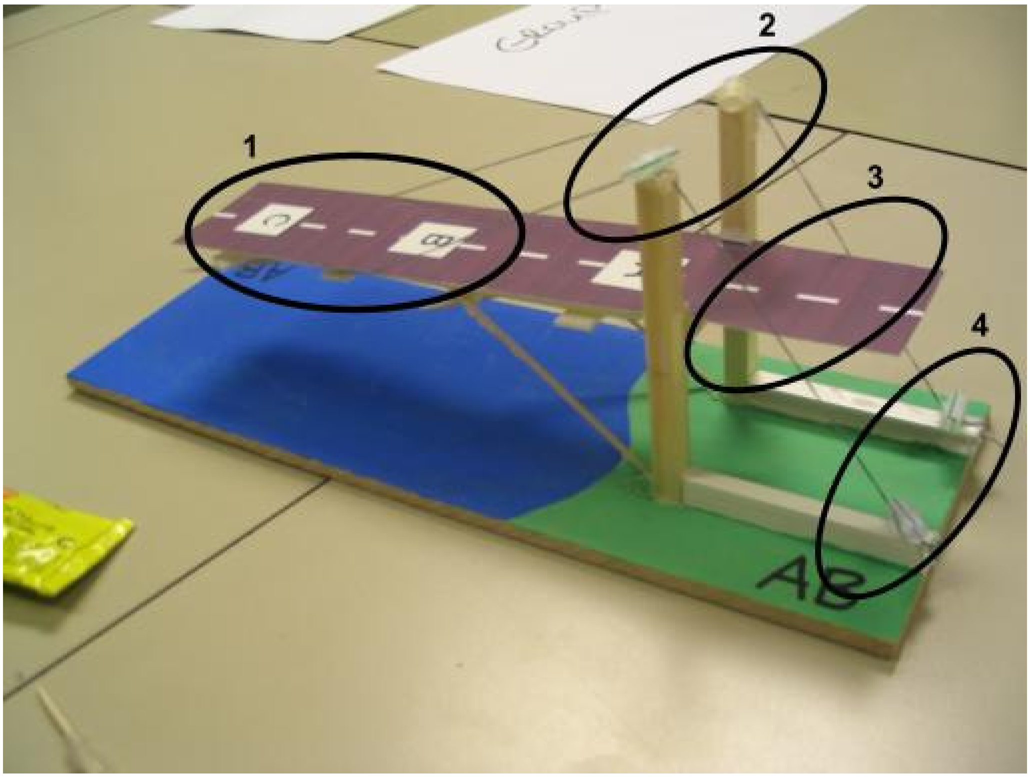


Figure 5.7 – A Given Development Crossing Three Zones

Because the arrangement of zones easily permits the orientation of the development to be determined, the lack of functional link means that this development would be denoted as: Thread (Zones A, C & D).

5.2.5.3. The Amount of Material Used in Developments

Reviewing a selection of the photographs also indicated that groups made use of different amounts of materials for given developments. Inclusion of this factor allowed for the type, placement and amount of material used to be mapped over time. Though there were numerous instances in the photographs that depicted the use of large quantities of a given material, such as tape, caution must be taken with both the level to which a photograph may tell of an ‘amount’, and in what terms amounts are to be described. It is clearly challenging and broadly unnecessary to try and ascertain figures to describe the exact quantities of materials applied, however, and on a less precise level, it was possible to make appropriate judgements.

The nature of the photographs and material use was not such that thresholds could be reliably applied to delineate ‘amounts’. This is as true for the excessive use of material as it is for insufficient use of material. From a static photograph, however, it is far easier to visually ascertain instances of the former than it is the latter. What may seem visually insufficient for a given development, can simultaneously satisfy the functional requirements insofar as the photograph does not depict any structural failure. The study hence only accounts for instances where comparatively large amounts of a given material have been employed. The judgement about what constitutes large in a relative sense will be based upon the immediate context of the given development within the structure and the nature of material use seen by other groups within the sample. In instances where it was deemed that groups had used large quantities of a given material, the normal weighting of 1 was increased to 2 for the development in question.

5.2.5.4. Functional Advantage & Aesthetic Developments

This constitutes the final dimension of this approach and is concerned with the extent to which a given development actually improves or benefits the functional performance of the solution. Developments such as the addition of flags that were never intended to improve the functional performance of the solution were simply recognised as aesthetic. It is necessary, however, to define what constitutes functional advantage and how it is signified within photographs.

The primary concern regarding this is that, in an engineering sense, functional performance is normally determined through some form of physical testing. Whilst this was done for the final solutions, it was clearly not possible to test the effects of every change to the solution. As such, functional performance must be recognised in the context of the global solution as well as the individual developments while at the same time, acknowledge the limitations associated with the extent to which a 2D photographs can be used to determine this for a 3D solution.

As was true with material quantity, no magnitude or numeric values can be ascribed to developments in terms of functional advantage. Judgements were therefore based upon a qualitative analysis of the development and its configuration in the context of the surrounding structure to which it relates. The limitation to this is that such judgements do not constitute proof of advantage in the measurable sense, but rather infer that a given change is very likely to be good or poor.

The following two examples consider instances in the data set where the functional advantage offered by a development was characterised as good, and, where it was considered to be poor.

Example 4: Good Functional Advantage

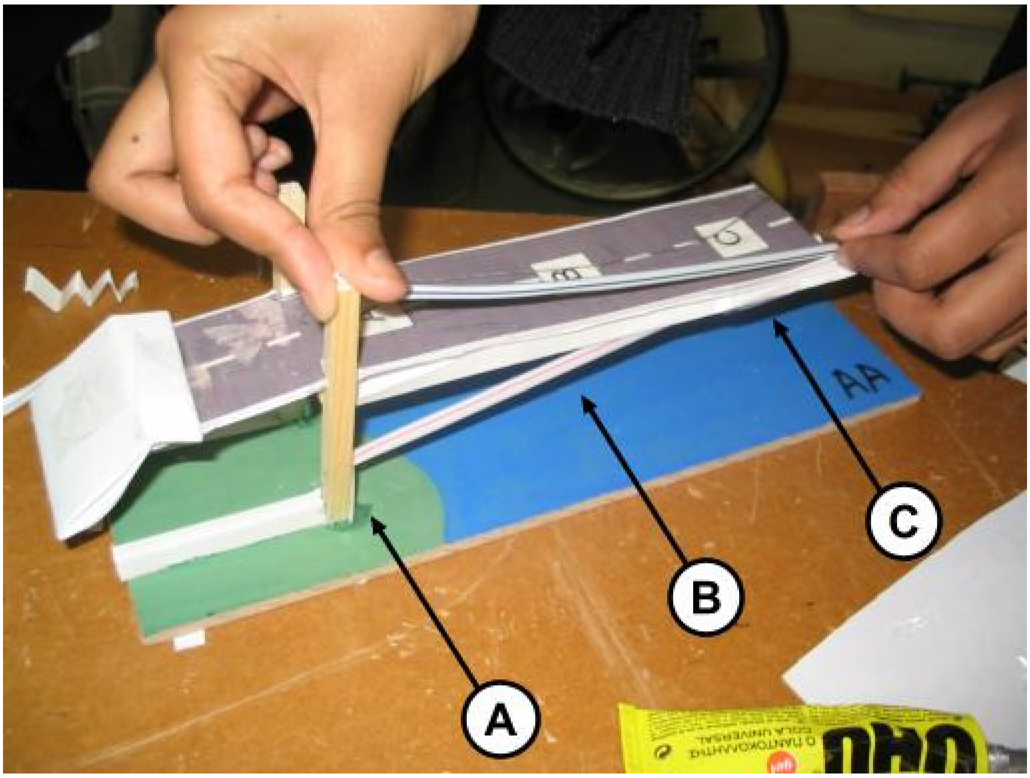


Figure 5.8 – Example of a Development Offering Good Functional Advantage

As shown in Figure 5.8, the use of the straw at position B under the road surface is configured to achieve triangulation, which, in turn, is likely to increase rigidity, lower movement and enhance overall strength. The choice of material is good under compressive loading in comparison some of the other materials available. In addition, there is evidence of anchoring with glue at Point A and tape at Point C (confirmed by additional photographs). These factors suggest that functional advantage has been added to the overall solution by this development.

Example 5: Poor Functional Advantage

By contrast, Figure 5.9 shows a development made using the plastic strips at Point B, which appear on both sides of the bridge (confirmed by additional photographs). These are seen to provide little to no functional advantage. They are fastened in place with tape and rest upon a straw at Point A. This offers little by way of rigidity and, even if a solid upright was achieved, the fact they are positioned so close to the turning point of the cantilever at Point C, means that they do little to resist its tendency to rotate about this point. In practice, it is likely that the bridge would perform in more or less the same way whether this development was present or not.

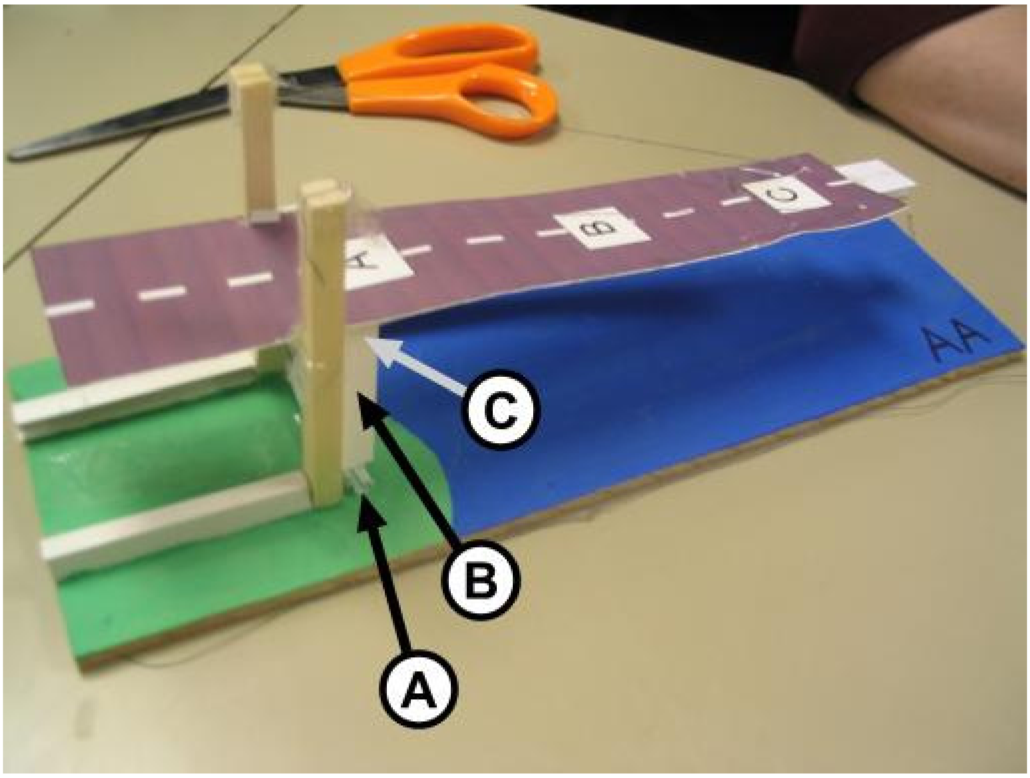


Figure 5.9 – Example of a Development Offering Poor Functional Advantage

5.2.6. A Coding Matrix for Photographic Analysis

A matrix system was developed in order to combine all of these factors and facilitate further analyse of each solution over time. The coding matrix was developed from the following specification:

The coding matrix must:

1. Map developments in terms of ‘samples’ over time.
2. Account for cumulative counts and instantaneous counts such that additive and subtractive developments can be shown.
3. Allow material-based developments to be linked to the zones in which they occurred.
4. Indicated whether relatively large quantities of material have been used for a given development.
5. Categorise a given development as aesthetic or as affording good or poor functional advantage.

Figure 5.10 shows a section of the resultant matrix, which was used to individually code

228 photographs. The summative questionnaire completed by pupils after finishing their solution was also drawn upon to aid validation of the photographic data (Appendix 7). The completed analysis is too extensive for inclusion in this document.

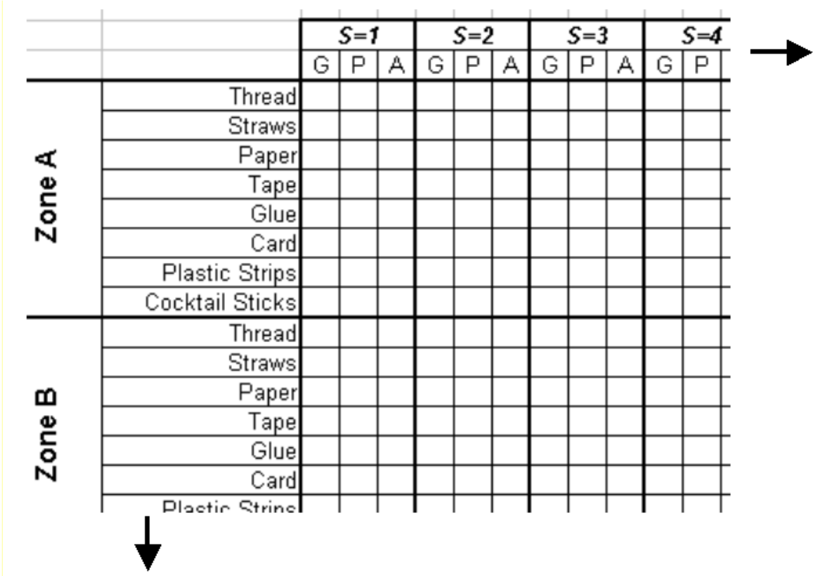


Figure 5.10 – Example Section from the Photographic Coding Matrix

From this, a range of tables and plots were produced that described different aspects of the development of the solution.

5.3. The Selection of Best & Poorest Solutions

Of central import to addressing the main research question was the successful identification of a cohort of the best solutions, and of the poorest, from the overall sample of 13. The difficulty in doing this was three fold. Firstly, the physical form taken by the solutions was not one in which they were either correct or incorrect, but rather, representative of an extensive range of variation and degrees to which success criteria were met. Secondly, as discussed in the previous chapter, there are possible risks regarding the Halo Effect and Contamination due to the researcher having observed the development of these solutions beforehand. This required measures to be taken to substantially reduce the possibility that solutions were chosen, consciously or otherwise, to satisfy pre-conceived notions the researcher may have of what leads to a better or poorer solution. Thirdly, for findings to be credible, the cohorts had to genuinely represent, as far as possible, the best and poorest solutions from the sample.

A Modified Delphi Technique, in conjunction with supporting data sources, was employed as a means of addressing these difficulties. Results from each area were combined into a solution matrix that allowed solutions to be placed in rank order. From thirteen groups within the study, four at either end of the ranked list formed the best and poorest cohorts. The data sources drawn upon in doing this were:

1. The level of physical development (from the photographic analysis matrix)
2. Solution performance (rank order of performance under loading by class)
3. Selection by expert panel (a Modified Delphi Technique using eight experts)

5.3.1. The Physical Development of the Solution

The level of physical development was determined from the structured analysis of the photographic data, the results of which are shown in Table 5.2. This breaks down the level of development by zone.

Physical Development of the Solution by Group						
	% Development by Zone					
Solution	***A***	***B***	***C***	***D***	***E***	***Total n***
Group 1	12.9	19.4	29.0	29.0	9.7	**31**
Group 2	14.0	0.0	35.7	50.0	0.0	**14**
Group 3	7.3	19.5	17.1	34.1	22.0	**41**
Group 4	33.3	15.2	18.2	27.3	6.1	**33**
Group 5	0.0	27.8	19.4	30.6	22.2	**36**
Group 6	5.0	15.0	10.0	50.0	20.0	**40**
Group 7	0.0	13.0	21.7	47.8	17.4	**23**
Group 8	9.1	9.1	18.2	50.0	13.6	**22**
Group 9	26.5	23.5	5.9	32.4	11.8	**34**
Group 10	5.9	11.8	8.8	50.0	23.5	**34**
Group 11	11.1	0.0	25.9	44.4	28.5	**27**
Group 12	6.5	0.0	15.2	56.5	21.7	**46**
Group 13	3.0	12.1	9.1	33.3	42.4	**33**
Averages	10.4	12.8	18.0	41.2	18.4	**31.8**

Table 5.2

It is recognised that, on its own, this does not inform on what constitutes good and poor solutions. A lower level of development may mean that a solution is more efficient in terms of its design and use of materials. This did, however, allow for consideration of key areas for development (e.g. Zones C & D, the road surface), against other data. The notion of efficiency is explored more in Chapter 6.

5.3.2. The Physical Testing of the Solution

At the end of the problem solving session, the groups within each class were given the opportunity to test their final solutions under staged loading up to 250g. Gaining an absolute measure of deflection was ultimately not possible for the following reasons:

1. Low overall structure integrity of some solutions resulting in deflections in more than one area of the structure.
2. Partial or significant failure under loading.
3. Very small differences in deflection between one model and the next that sometimes did not remain constant under repeated loading or movement of the load.

Despite this, it was still possible to place the solutions in rank order for both the level of deflection and for the rigidity of the road surface. These two rank positions were combined to give an overall rank order of the groups within each class as shown in Tables 5.3 through 5.5. The primary success criterion 'Deflection' was given a weighting of 1.5.

Results of Physical Testing for Class 1					
	Deflection	**Rigidity**	**Total**	**Rank**	**Developments**
Group 1	3	4	8.5	2nd	**31**
Group 2	2	2	5.0	3rd	**14**
Group 3	4	3	9.0	1st	**41**
Group 4	1	1	2.5	4th	**33**

Table 5.3

Results of Physical Testing for Class 2					
	Deflection	**Rigidity**	**Total**	**Rank**	**Developments**
Group 5	4	4	10.0	2nd	**36**
Group 6	5	5	12.5	1st	**40**
Group 7	1	1	2.5	5th	**23**
Group 8	2	3	6.0	4th	**22**
Group 9	3	2	6.5	3rd	**34**

Table 5.4

Results of Physical Testing for Class 3					
	Deflection	**Rigidity**	**Total**	**Rank**	**Developments**
Group 10	2	4	7.0	2nd	**34**
Group 11	3	2	6.5	3rd	**27**
Group 12	4	3	9.0	1st	**46**
Group 13	1	1	2.5	4th	**33**

Table 5.5

As shown in all three classes, the rank orders of developments and performance corroborate each other in at least half of all instances. Of the exceptions to this, Group 11 achieved the second best level of deflections using 41.3% less developments than the group that achieved the least deflection, which suggests a more efficient structural solution (analysed further in Chapter 6). Furthermore, in all three classes, the lowest ranking groups were the poorest in terms of both deflection and rigidity reflecting the overall structural inadequacy arising from the interdependence between these two functional requirements. This relationship only held true for better performing solutions in Class 2 which indicated that poorer solutions were often more readily identifiable.

5.3.3. Selection by Panel of Experts (Delphi Technique)

It is recognised that there are any number of decision-making systems and approaches found within a vast range of areas from linguistics to management to medicine. Some of these are bespoke and developed for generating a level of consensus under specific circumstances (*see* Hererra et al, 1995; Delgado et al, 1997; Eklund et al, 2007; Xu, 2009; Raab et al, 2006; Hamilainen et al, 1992; DeGroot, 1974 and Nurmi, 1985). Some constitute more generic approaches that are seen as applicable to a range of circumstances. Four main recognised approaches are Brian Storming, Nominal Group Technique, Q Methodology and The Delphi Technique. Common to all of these is the objective of generating consensus.

Brainstorming is the least structured and most ill-defined of those listed. Nominal Group Technique is employed for creative decision making based on the judgements of a range of people with differing perspectives and backgrounds (*see* Delbecq et al, 1975; Claxton et al, 1980; MacPhail, 2001). Q Methodology is a structure system intended to explore the nature of subjectivity in decision-making. Though structurally, it bears similarity to the Delphi Technique in that there are rounds where people sort and rank statements, the focus is on the subjectivity associated with the process, rather than on simply generating agreement (*see* Cross, 1995; Brown, 1996). The Delphi Technique is, however, a structured decision making mechanism that encourages consensus from a range of individuals who are selected on the basis of their expertise in relation to the topic in question. The Delphi Technique was chosen from the aforementioned approaches for the reasons outlined next. An extensive and detailed description of the technique is given by Rowe & Wright (1999) and Linstone & Turoof (2002), amongst others.

1. It allows solutions from across the whole sample to be considered, in part addressing the limitation cited with the performance data.
2. It allows for the judgement mechanism to remain detached from this author, thus avoiding the risk that the study becomes engineered in some way.
3. It provides a systematic means of synthesising the judgements of experts towards a level of agreement; in no way can it produce statistically significant findings. Though it has been criticised in terms of forecasting and for its use in estimation (Woudenberg, 1991), the mechanism it provides is deemed appropriate for the purposes of this study.
4. Though the researcher is not involved in the decision making process, the requirement for experts to provide reasons for the decisions they give provides a basis on which to judge their credibility.
5. It can be facilitated electronically in a short time scale with no requirement for participating experts to meet in the same location.

5.3.4. Overview of the Delphi Technique

The process itself uses a small group of identified experts and a facilitator who is normally the researcher. Normally, it takes place over a series of between two and four rounds, although this can vary depending on the nature of the topic. Each round is administered using a questionnaire, the results of which are analysed to form a basis on which to design the subsequent round. In an example of forecasting (Gordon, 1994), experts may be asked to provide a predicted date for a Mars landing and state their reasons why. This would be analysed and the range of reasons and options identified. In the second round, this would be given back to all of the panel members and those members who hold an extreme opinion, in terms of all responses, would be asked to review the findings and reconsider their answer in light of the general findings. The responses from this round would then be synthesised and form the basis of a third round that would present the new group date and reasons for the landing. Each member would then be asked to re-assess their opinions in response to this, again providing reasons for their answers. The same process would again be applied to fourth and final round before the ultimate consensus is presented back to the group. As stated by Gordon (1994), this is tantamount to controlled debate. It is normal that, for each round, a threshold level is set beyond which a suitable level of consensus is achieved.

5.3.5. A Modified Delphi Technique for this Study

It is recognised that an original Delphi Method begins with an open-ended question. Modified Delphi's are recognised as those where a question is asked of a specific set of information; in this case, photographs and details of the groups final solutions. The Modified Delphi was carried out in four main stages: identification of experts, training of experts, administering and synthesis of first round, and the administering and synthesis of the second round. A suitable level of consensus was achieved after only two rounds. The process took approximately 10 days to complete.

5.3.5.1. Identification of Experts

Depending upon the nature of the subjects being explored and the size of the intended Delphi, the identification of experts can be a significant and lengthy undertaking. In this study, however, teachers were naturally defined as experts within this context. They provide a nexus of knowledge about both content and pupils that allows them to make uniquely informed judgements. Whilst Engineers may also possess the knowledge of content, they may have little to no understanding of what is typically expected by way of understanding and attainment from a thirteen year old pupil. The following criteria were used to identify ten expert panel members from the population of Secondary School Technology Teachers:

Panel members must:

1. Be practising teachers of technology education or have had at least five years of experience in this post.
2. Have a suitable level of technological content knowledge.
3. Have experience of teaching and assessing the work of S2 pupils.

4. Come from more than one local education authority.
5. Not teach at any of the schools participating in this study.

Initially, ten potential panel members were identified from three Local Education Authorities: Falkirk, Stirling and North Lanarkshire. They were asked to complete an on-line profiling questionnaire, which indicated that one of these panel members was currently undertaking their probationary year and failed to meet the criteria. One further panel member withdrew due to a change in personal circumstances, but as this happened before the first round was issued, there was no resultant mortality effect. This gave a group of eight experts who met all of the necessary criteria and agreed to participate in the Modified Delphi. The profiles generated by the questionnaires are given in Table 5.6.

	Profiles of Expert Panel Members							
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8
Practicing Teacher of Technology Education (Fully qualified & GTCS Registered)	✓	✓	✓	✓	✓	✓	×	✓
Retired Teacher of Technology Education (Number of years teaching experience shown)	×	×	×	×	×	×	28	×
Experience of setting, teaching and assessing work for S2 pupils.	✓	✓	✓	✓	✓	✓	✓	✓
Experience of teaching 5-14/ACfE/Technology Common Courses	✓	✓	✓	✓	✓	✓	✓	✓
Experience of teaching Graphic Communication	✓	✓	✓	✓	✓	✓	✓	✓
Experience of teaching Craft & Design	×	✓	✓	✓	✓	✓	✓	✓
Experience of teaching Technological Studies	✓	✓	✓	✓	×	✓	✓	✓
Experience of teaching Product Design	✓	×	✓	✓	✓	×	✓	✓
Experience of teaching Practical Craft Skills	✓	✓	×	✓	×	×	✓	✓

Additional jobs or qualifications, other than those for teaching, that relate to or enhance your expertise in technology and/or technology education.	Worked for 1 year as architectural technician. Studied architecture for 2 years at Strathclyde University.	Presently SQA - Marker - Higher Graphic communication SQA – Central Verifier Graphic Communication Past SQA - Marker - Standard Grade Graphic Communication	BSc Aeronautical Engineering Development engineer for Marconi Avionics 1955 - 1994	Working in Buccleughs engineering fabricating engine parts from drawings. Sky television technical department dealing with analogue then introducing digital television. Dealing with data collection and registration processes with highly stressed and high profile customers.	Medical technician Arborist	I was a mining engineer before entering the teaching profession. I have had around ten years experience as a marker of Higher Grade Graphic Communication. I am a member of the interviewing panel for the awarding of Arkwright Scholarships.	Planning Engineer, North Of Scotland Hydro Electric Board for 7 years. Working on overhead & underground networks , construction & buildings. SQA moderator for Technological Studies at Standard Grade, Higher & SYS Project reports and on the SQA TS Intermediate examination revision panel. Curriculum Development Officer for Central Region Technological Studies (3 years).	Former Professional Engineer, B. Eng qualified.

Table 5.6

As shown, all panel members are highly qualified with regard to the technological knowledge; many from engineering backgrounds or are experienced in delivering the technological studies area of the technology curriculum.

5.3.5.2. Training of Expert Panel Members

Upon agreeing to participate, all panel members were contacted and the process was discussed with them. They were made aware of the reasons for undertaking the process, the mechanics of the process itself, what the expectations were from them, and the necessary information to form a basis on which to make judgements. They were also told that they could contact the researcher by email at any point if they had questions or required clarification of anything. Given the role the Modified Delphi is playing within this study, what the expert panel were told and were not told was critical to maintaining objectivity.

The expert panel were made explicitly aware of the following:

1. Stage and average number of the pupils in a group.
2. Core aspects of the structures unit that the pupils had learnt about.
3. Details of the problem-solving task and how it was presented to the pupils.
4. Success criteria given to pupils.
5. Resources made available to pupils, including time.
6. That this Delphi was one of several methods that would be used to decide upon which groups were the best and worst. The models, for example, had already undergone physical testing.

The following information was necessarily withheld from the expert panel:

1. The results or findings from any other form of analysis or testing carried out on the models.
2. Any findings about the problem solving activity of pupils prior to the completion of their final solution.
3. Any and all demographic information about the groups or pupils themselves. This included, but was not limited to, the participating schools, the gender of groups or the classes to which solutions belonged.
4. The identities of any other expert panel member.

5.3.5.3. Execution of the Modified Delphi

A pack of information was compiled in a format that could be emailed to panel members (Appendix 9). This included all necessary guidance notes, photographs and configuration drawings of the solutions as well as e-forms on which to record judgements and reasons. The reasons given allowed a judgement to be made as to whether the choice was substantiated in terms of the information made available. In all rounds, e-forms were emailed back to the researcher upon completion. Experts were instructed to undertake this task entirely on their own and no one panel member was able to identify the other experts involved or was aware of their profile.

The threshold level for consensus was defined at 75%, or six out of eight. Conversely, the threshold for extreme views was set at 25%. Individual panel members to whom this applied were asked to reconsider their judgement in view of the reasons given by other experts.

5.3.5.4. Modified Delphi: Round 1

Experts were asked to review the photographs and configuration drawings in light of the task and the structures unit, and choose four solutions from thirteen that represent the 'best', and four from thirteen that represent the poorest. There was no requirement to rank these as this would naturally occur during synthesis. Tables 5.7 and 5.8 show the quantitative results from this round in rank order. Threshold levels are marked at the top and extreme views highlighted individually.

Votes for Best Groups (M-Delphi Round 1)									
Solution Number	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Freq

5	1	1	1	1	1	1		1	7
6	1			1	1	1	1	1	6
8	1	1	1		1		1		5
10		1		1		1			3
12				1			1	1	3
2			1					1	2
3		1					1		2
9					1	1			2
7			1						1
11	1								1
1									0
4									0
13									0

Table 5.7

Votes for Poorest Groups (M-Dephi Round 1)									
Solution Number	**Exp 1**	**Exp 2**	**Exp 3**	**Exp 4**	**Exp 5**	**Exp 6**	**Exp 7**	**Exp 8**	**Freq**
7	1	1		1	1	1	1	1	7
13	1	1	1		1	1		1	6
4		1		1		1	1	1	5
2	1			1	1		1		4
1		1	1					1	3
10	1		1						2
11					1	1			2
3				1					1
5							1		1
9			1						1
6									0
8									0
12									0

Table 5.8

This initial round readily identified Groups 5 and 6 as having produced the best solutions and Groups 7 and 13 as having produced the poorest. These were accepted having reached the threshold for consensus. A degree of consistency in expert judgement is observed in that these solutions occupy the opposite end of the rank order for their opposing cohorts. These four groups were removed from the second round of the Delphi.

5.3.5.5. Modified Delphi: Round 2

During this round, the four groups identified in the first round were removed and experts were asked to make the same judgements as before with the remaining pool of nine solutions. The experts were also issued with the results from the first round. This included the tables shown above along with each of the corresponding reasons given. Any experts who nominated solutions that received two votes or less were asked to re-consider their decision in light of this additional information.

The results from this round are shown in Tables 5.9 and 5.10, which indicate that groups 8 and 12 were identified as producing the best solutions, and 2 and 4 were identified as producing the poorest from the remaining groups.

Votes for Best Groups (M-Delphi Round 2)									
Solution Number	**Exp 1**	**Exp 2**	**Exp 3**	**Exp 4**	**Exp 5**	**Exp 6**	**Exp 7**	**Exp 8**	**Freq**
8	1	1			1			1	4
12	1			1	1			1	4
10		1		1		1			3
9						1	1		2
2			1						1
3							1		1
7			1						1
11									0
1									0

Table 5.9

Votes for Poorest Groups (M-Dephi Round 2)									
Solution Number	**Exp 1**	**Exp 2**	**Exp 3**	**Exp 4**	**Exp 5**	**Exp 6**	**Exp 7**	**Exp 8**	**Freq**
2	1	1		1	1		1	1	6
4		1		1	1	1	1	1	6
10	1		1						2
9			1						1
11						1			1
1									0
3									0
8									0
12									0

Table 5.10

5.3.5.6. Face Validity of Expert Judgements

An examination of face validity was carried out to ascertain the extent to which experts reasons were supported by the information that was made available to them (Appendix 10). The validity key shown in Table 5.11 was used.

Face Validity Levels	
High	All the components of the reasons provided can be substantiated by the information given to the experts.
Medium	Some of the components of the reasons provided can be substantiated by the information given and some cannot.
Low	None of the components of the reasons provided can be substantiated by the information given.

Table 5.11

Of the 43 reasons given in identifying the groups in each resultant cohort, the face validity was judged to be high in all but six cases, where it was judged to be medium. In these instances, part of the written reason had insufficient detail, was unclear or did not relate directly enough to what was being asked.

5.4. Identified Cohorts

Synthesising the data from the physical testing, the development level and the expert panel allowed the cohorts in Table 5.12 to be identified. The full synthesis matrix can be found in Appendix 11.

Overview of Identified Cohorts		
Rank	**Cohort 1 Best Solutions**	**Cohort 2 Poorest Solutions**
1^{st}	Group 5 (Best)	Group 7 (Poorest)
2^{nd}	Group 6	Group 13
3^{rd}	Group 12	Group 4
4^{th}	Group 8	Group 2

Table 5.12

It should also be noted that this author is satisfied that this process has produced a representative sample from those solutions produced.

These cohorts were used to facilitate the exploration of differences between groups that performed well and groups that performed poorly as described in Chapter 6.

Chapter Six

Results & Analysis

6. Results & Analysis

This chapter reports on and presents the analysis and results from the data gathering instruments and approaches defined and described in Chapters 4 and 5. The arising data set was both complex and extensive. The salient features and evidence that ultimately inform the research question will be presented and analysed in four sections:

Section 1: Ecological Consistency & Academic Performance

This draws on the data gathered during the structures unit and assesses the overall consistency between the experiences and knowledge of each participating class as a backdrop against which further analysis is carried out.

Section 2: Initial Comparison of the Two Most Contrasting Groups (Dyad 1)

This describes the first stage in addressing the research question wherein an in-depth, inductive comparative analysis of the best and poorest groups from each cohort was undertaken. Findings from this established a range of specific frameworks mapping the areas in which differences lay. These frameworks were then tested against the remaining groups in each cohort.

Section 3: Comparison of Remaining Dyads

This section explores differences between those groups in the remaining three dyads that arose from applying the frameworks established from the initial comparative phase. Though shorter than the previous analytical stage, it is similar in that it can be seen as a series of horizontal analyses.

Section 4: Cohort Analysis

This final section analyses the differences and similarities that were established in the previous two sections in terms of the good and poor cohorts. This can be conceptualised as two vertical analyses providing summative findings that directly address the research question.

i. The Role of the Teacher

In line with the decisions made in Chapter 4, Teachers were encouraged to interact with and respond to pupil questioning as they would normally, as well as deliver the necessary content associated with the study in their own style.

ii. The Role of the Researcher

With the learning being led by the teachers, the researcher was present within the classrooms as an observer-participant. Prior to both the unit of work and the main problem-solving task, the researcher spoke to the pupils in each class to briefly remind them of the reasons for the study and clarify the observational role. Pupils were also told that nobody other than the researcher would be allowed to listen to what was on the audio tapes and that the researcher would not share that information directly with the classroom teacher. Pupils were also made aware that questions and discussion should be directed to the classroom teacher as normal.

iii. Class Groupings

In accordance with the rationale developed within the methodology, teachers were asked to break the class into single gender groups that, in their professional judgement, would work well together. Table 6.1, shows the resultant groupings and the number of pupils in each. Complete profiles for each group can be viewed in Appendix 19 (CD-Rom).

Class Groupings			
	Group Number	**Gender**	**Number of Pupils**
School 1 (Class 1)	1	F	4
	2	F	4
	3	M	4
	4	M	5
School 2 (Class 2)	5	F	4
	6	F	4
	7	M	4
	8	M	4
	9	M	4
School 3 (Class 3)	10	M	3
	11	M	3
	12	F	4
	13	M	3

Table 6.1

6.1. Ecological Consistency & Academic Performance

The following section describes the analysis of the delivery of the structures unit prior to the main problem-solving task in terms of lesson content & teaching approaches, and the pupils' written attainment in the task sheets. Data from the following five data sources were drawn upon in doing this:

1. Unstructured Observational Notes
2. Structured Observational Schedule for Lesson Content
3. Pupil Task Sheets
4. Teacher Questionnaires (Appendix 6)
5. Notes from Planning Meetings with Teachers

6.1.1. Lesson Content & Teaching Approaches

The structured observational protocol broke the Structures Unit into five sections and a total of 40 discrete content indicators. Results from this observation show that the entire course content was delivered to all three participating classes (*see* Appendix 9 for Results). Despite the option to deliver the unit of work over three periods, all three schools did it within 2 periods as was recommended. Table 6.2 indicates the distribution of course content across each of these periods.

Distribution of Course Content for Each Class by Period			
	Number of Content Indicators Covered in Lesson 1	**Number of Content Indicators Covered in Lesson 2**	**Content Indicators Missed**
Class 1	30/40 (75%)	10/40 (25%)	None
Class 2	30/40 (75%)	10/40 (25%)	None
Class 3	33/40 (82.5%)	7/40 (17.5%)	None

Table 6.2

Overall, the distribution of lesson content was broadly similar to that suggested in the planning meetings and unit support notes (Appendix 1). The only discrepancy was that Class 3 was introduced to the concept of triangulation at the end of the first lesson rather than the start of the second as was observed with the other two classes. This meant that the more rapid coverage of initial content allowed more time spent on cantilevers and turning moments; the two most conceptually demanding areas and those which relate most directly to the problem solving task. Although the overall effect this may have upon the problem-solving task is difficult to determine, Class 3 scored 90% for this section compared with a significantly lower average performance of 49.9% from the remaining two classes.

The unstructured observation showed that all three teachers employed a variety of examples at regular points throughout the course, instigated by them and by pupils themselves. These served to help pupils contextualise learning and actively make contributions to questioning and discussion. Figure 6.1 shows the five sections of the course in the order taught and lists some of the key examples observed within lessons. These were extracted and compiled from the hand-written observational notes.

	Class 1	Class 2	Class 3
Three Main Types of Bridges	Included famous bridges, including forth road bridge and stone arch bridges across canals.	No local bridges mentioned but made use of railway and famous bridges.	Examples of local bridges as well as famous bridges such as the golden gate bridge.
Tension & Compression	Pillars in high rise car parks, tug of war and a range of pupil-familiar objects.	Rope, string, pencils, pillars holding up oil rigs, elastic bands and tug-of-war.	Tug-of-war, range of familiar objects and rolled paper as a material that could be configured for each.
Ties & Struts	Only examples of strcutures discussed.	Main example of compression was the legs of a stool when sitting on it.	Peoples legs designed for compression and a complex example of a bicycle spoke holding a bike up.
Triangulation	A range of examples were given of where it could be found in the man-made environment.	Included man-made and natural examples such as a fly's wing and tree branches.	Mainly man-made environment but also covered stability gained in standing with feet further apart.
Cantilevers & Turning Moments	Motorway brigdes and walk-overs as well as shelves and diving boards.	Mainly bridges but rulers were used to create cantilevers that pupils could interact with.	Shelves, bridges and a more detailed example of the forth rail bridge as a cantilever system was looked at.

Figure 6.1 – Key Teacher Examples for given Course Sections

It can be seen that all three classes were exposed to a range of examples allowing the concepts involved to be considered in a range of situations, both more and less familiar to them. Whilst there was a clear recurrence of certain examples, such as the forth road bridge, Figure 6.1 also illustrates three emergent differences. Classes 1 and 2 shared a similar type and complexity of example, whilst Class 3 made use of some additional examples that were far more conceptually demanding such as bicycle spokes. This may be a reflection of the differing emphases in departmental curricula in that although no pupils within the sample had learnt about structures prior to this study; it constitutes a significant part of the curricular content in School 3 from S3 onwards. Another difference was in the way in which the examples were explored. Classes 2 and 3 were noted as exploring examples more 'interactively' with a range of pupils having to leave their seats to assist and take part in the demonstrations, whilst Class 1 explored these almost exclusively through discussion or teacher demonstration.

6.1.2. Responses to Teacher Questionnaires

Overall, the responses from the teacher questionnaires (Appendix 6) demonstrated largely similar effects across classes:

Vignette of Response from Teacher of Class 1

The pupils seemed more responsive with one or two appearing very keen and excited. The class enjoyed the lessons on the unit of work but pupil attention span lowered towards the end of the second period; though this is normal. The behaviour of the class was normal and there were no notably different characteristics during the unit.

Vignette of Response from Teacher of Class 2

Overall, the pupils appeared to be more motivated and keen to answer questions, though no change was observed in how they answered. The class appeared very interested, though there was a lot of information imparted and pupil tasks were quite short - the class were not as attentive as in previous lessons. The behaviour of the class was no different from normal and pupils who did not normally involve themselves were seen to participate in tasks and paired work.

Vignette of Response from Teacher of Class 3

Pupils seemed more interested in getting answers correct and were more enthusiastic in their responses. During the second lesson, pupils were confident in answering questions having been able to prove their answer through the activities; this practical aspect, along with the powerpoint, kept them more attentive than normal. Pupil behaviour during the first lesson was normal though seemed better during the second. Pupils seemed quieter during the first lesson showing a high degree of interest and shared in completing tasks.

6.1.3. Summary of Ecological Consistency

Overall, the general approach taken by all three teachers was remarkably similar and there were no significant differences noted with regard to content that would have resulted in one class gaining a distinctly different experience or exposure to any other. In view of the above evidence, the level of ecological consistency between participant classes is considered to be high.

6.1.4. Curricular Exposure & Academic Performance

This section reports on the pupils' curricular exposure prior to the study and analyses the knowledge and understanding gained by pupils during the structures unit.

6.1.5. Curricular Exposure within Technology Subjects

The structures problem chosen for use within this study forms part of the technological studies section of the curriculum. Discussion during the planning meetings revealed that whilst only two of the three schools offer this to pupils in S1 or S2, no pupils in the sample had undertaken any prior work on structures at the point of participation. It is also relevant to note that all pupils had undertaken some form of practical, three-dimensional construction, although the associated design content dealt only with two-dimensional concepts.

6.1.6. Knowledge & Understanding in the Structures Unit

As part of the Structures Unit, pupils individually completed a series of five task sheets that were marked to provide performance figures for each pupil within the sample (Appendix 2). The five task sheets include a range of questions such as knowledge of types of bridges, however, only selected questions from the task sheets were used to inform on the three core areas of tension & compression, triangulation and turning moments. The class attainments for all questions in the task sheets are shown in Table 6.3. Class attainments for only the core areas are given in Table 6.4.

This indicates a clear rank order of performance with both overall performance and with performance adjusted for pupil absence. Mortality effects due to pupil absence was something over which the study had little control and resulted in a number of task sheets not being issued to pupils. The adjustment for absence gives the attainment per class of those sheets that were issued to pupils rather than for the total number of marks initially available to a class. Although there is an attainment difference in excess of 13% between the best and worst performing classes, it should be recognised that the average attainment of all classes fell within the 7th and 8th deciles, indicating a very good overall level of knowledge and understanding. The magnitude of the standard deviation values inversely reflected the overall rank order of performance indicating that, within this sample, as overall pupil attainment dropped, the degree of variation between individual pupil attainments increased. As such, Class 3 showed the greatest level of attainment and consistency thereof between pupils.

Class Performance in Unit Task Sheets			
	Class 1	**Class 2**	**Class 3**
Number of Pupils (n)	**17**	**20**	**17**
Overall Class Performance	61.1%	79.35%	81.2%
SD of Pupil Raw Scores	6.31	3.99	5.07
Class Performance (Absence Adjusted)	74.4%	81.3%	87.9%
SD of Pupil % Scores (Absence Adjusted)	15.5	11	5.7
% Overall Absence	17.6%	2.5%	8.8%
% Pupils Absent for 1st Period of Unit	23.5%	0%	6%
% Pupils Absent for 2nd Period of Unit	11.8%	5%	11.8%
Rank Order of Performance	3rd	2nd	1st

Table 6.3

Performance by Class in Core Areas of Structures Unit				
	Tension & Compression	**Triangulation**	**Turning Moments**	**Class Average**
Class 1	83.3%	80%	48.9%	70.7%
Class 2	92.0%	84.2%	50.9%	75%
Class 3	92.5%	93.3%	90%	91.9%

Table 6.4

6.1.7. Summary of Performance in the Structures Unit

Notwithstanding the specific differences discussed above, classes exhibited a very high level of attainment (70%+) from the structures unit with the most notable deficiency in relation to the concepts and principle associated with moments of force. Class scores were also consistent with an attainment range of just 13%.

6.2. Inductive Comparison of the Two Most Contrasting Groups

This analytical phase sought to begin exploring the differences between the least and most successful groups in terms of the initial research question with no stated hypothesis or prediction as to what these would be (*see* Chapter 5 for Grounded Theory Discussion). Whilst the modes, processes and knowledge types identified in the conceptual framework acted as a lens through which to explore differences, the approach taken at this stage was characteristically inductive in nature as described by (Strauss 1987, *in* Miles & Hubberman, 1994). During this stage of the study, the aims were two-fold:

1. To identify the key emergent differences between, and characterise the activity of, the groups that produced the best and poorest solution.
2. Structurally define the associated processes and knowledge, using the data and, in view of the conceptual framework.

Successfully addressing these aims provided a basis against which the activity of the remaining six groups could be compared.

6.2.1. Structure of Analysis

The analytical structure presented in Figure 6.2, was based upon the rank orders established in the identification of the two cohorts (Stage 2) and accounts for both this and the subsequent stage of analysis. The successive structure depicts four dyads that were formed by matching groups of equal rank from each cohort.

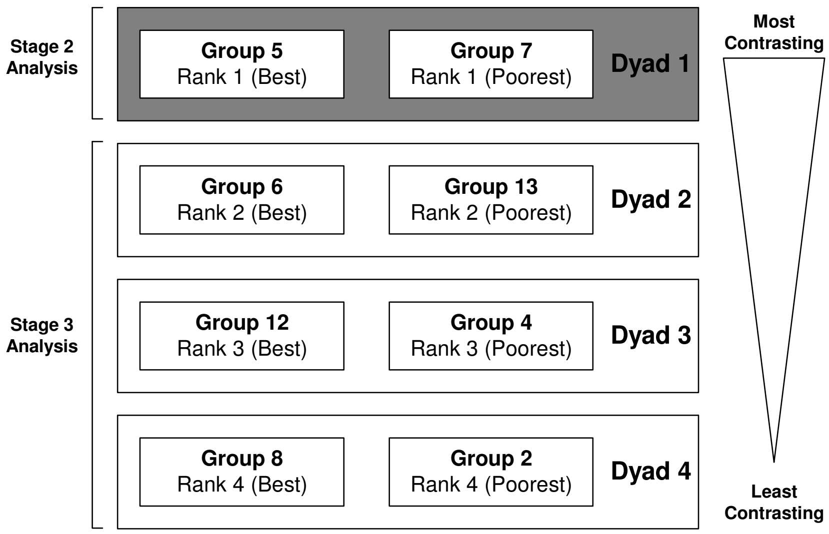


Figure 6.2 – Structure of Analysis

Not only did this provide a manageable structure that was intrinsically logical to this study but also identified the two most contrasting cases necessary for the inductive analysis in this stage.

6.2.2. Data Sources Used

The five main data sources drawn upon for this stage are detailed below. These are the same sources drawn upon for all remaining analytical stages and it is through these, that a detailed and corroborated represention of problem solving activity was established. Of these data sources, the audio recording, photographs, observations and pupil sketches generated the most immediate and local data relative to the task itself. The teacher questionnaires and interviews were retrospective.

i. Audio Recordings of Group Verbalisation

This constitutes the core source of data in that it is both the 'closest' to the phenomena under investigation and was continuous throughout the problem solving activity. The data was managed and analysed using the NVivo 8 software package as raw audio files. As such, it was not transcribed but rather coded directly to the digital waveform. Within this software, codes are referred to as 'Nodes' and can be either free of structure of hierarchical. Free nodes were employed within this study to avoid the risk of prematurely, and possibly erroneously, imposing a structure upon aspects of the phenomena. Any hierarchical structure that emerged during the analysis was determined manually. Coding this data to a range of free nodes gave rise to a pattern of coding stripes representative of the aspects of processes and knowledge concerning this study. Given that there were seveal pupils interacting in the task, that the activity was explored through a number of conceptual levels, and that granularity of coding could sometimes be as fine as a single word, the resultant coding density and complexity was extremely high. An excerpt of this is shown in Figure 6.3.

In preparation for analysis, the digital audio data was segmented into samples at points to coincide with the photographs of the developing solution. This was primarily done to facilitate easier cross-referencing between data sources but also meant that working files were more manageable in size. In total, over 12 hours of audio data were coded and analysed within this study. A breakdown of this by sample and duration for each class is given in Appendix 10.

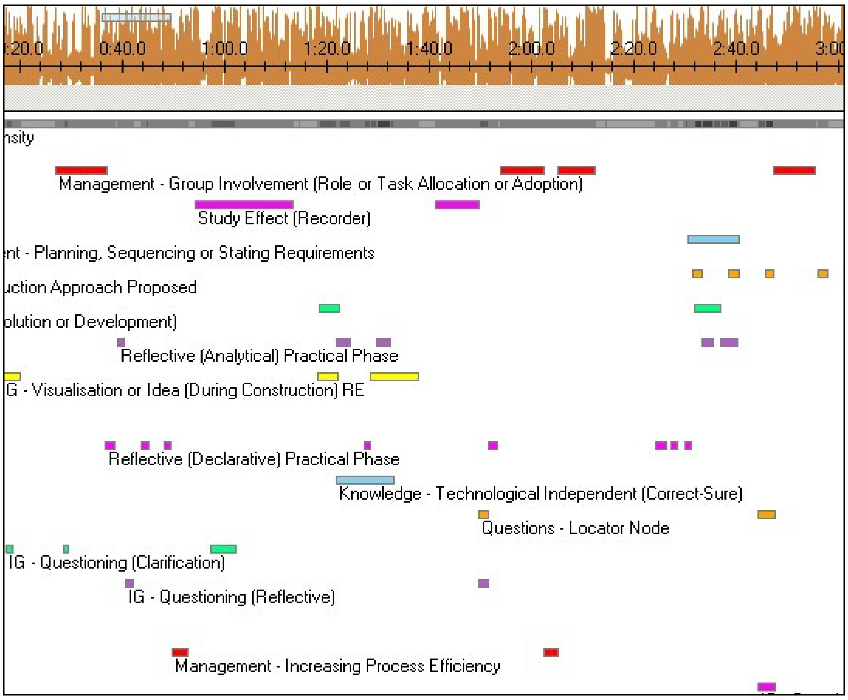


Figure 6.3 – Excerpt of Process Coding Bars in NVivo 8

Within the body of this thesis, references to raw audio data utilise the following code: (Group X, S=Y, Start-End), where ‘X’ = group number, ‘Y’ = sample number, ‘Start’ and ‘End’ = start and times of the sample in minutes (m) and seconds (s); ‘n’ refers to the number of counts of a given code (e.g. n=14). The ‘Group’ and ‘End’ terms of reference will only be used when contextually appropriate and all times given will be rounded to the nearest second. Additionally, the excerpt number refers directly to the corresponding audio sample which can be accessed from the accompanying CD-Rom.

Where excerpts from a group’s discourse have been included in the body of the thesis, the identifiers for each pupil are true only within the given excerpt. Pupil 1 in excerpt X may not be Pupil 1 in excerpt Y. Because this investigation employs the group as the unit of study, it was not necessary to identify pupils through events and activity.

ii. Time-Based Photographs of Developing Solution

This constitutes an interval-based data source that spans the duration of the problem solving activity. As stated previously, these correspond to the samples of audio data and it is important to note that they depict the development of the solution at the end of a given sample, rather than at the start. Following the structures analysis described in the previous chapter, a range of results were generated that will be referred to throughout the remaining sections. These include development plots, configuration schematics and quantitative data on the use and placement of materials.

iii. Structured Observational Data

This constitutes a time-based data source generated at four points during the problem solving process. Codes recorded during these observations were counted and the results displayed as tables and bar graphs. Each observational session lasted for the duration of a single sample (approximately 3-4 minutes) thus allowing for synchronisation with the photographic and verbal data. The quantitative results for the structured observation are provided on the CD-Rom and will again be drawn upon at key points throughout the analysis. The purpose of this data is only to corroborate and deepen the understanding of aspects that arise from the other core data sources at key points, not to provide a continuous account of activity.

In addition to those above, data from all other sources will be drawn upon as necessary, including, but is not limited to pupils' sketches, teacher and pupil questionnaires.

6.2.3. The Inductive Analytical Approach

The data sets established during this study were both extensive and complex and there were an endless number of variables or themes which could be considered in addressing the research question. Consequently, it was necessary to establish those aspects of the conceptual framework that were relevant to this particular study and, hence, to answering the research question. Miles & Hubberman (1994), outline a spectrum of approaches to analysing and coding qualitative data ranging from *a priori* coding using pre-defined schedules through to inductive or grounded coding. The nature of the conceptual framework meant that *a priori* coding was possible and, indeed, was trialled with the audio data of one test group. In reviewing these codes against the data, it was quickly realised that they offered little in the way of new findings and, more significantly, masked the nuances from which characteristics of interest could emerge. Because of this de-sensitising effect, it was decided to undertake a more ‘open’ analysis in this initial stage; similar to the inductive approach advocated by Glaser & Strauss (1967). Here, rather than beginning with a pre-defined ‘start-list’, codes emerge from consideration of the data within its own context and in mind of the conceptual framework. Importantly, and as asserted by Miles & Hubberman (1994), this type of approach does not abandon structure and still seeks to match observations of the data to a theory or set of constructs. Further to this, Strauss (1987) *in* Miles & Hubberman (1994), advocates that, in the early stages of such analysis, choosing two contrasting cases serves to sensitise the researcher to the differences between them and can give rise to subsequent points of interest. This approach was therefore employed as it lies at the core of the main research question.

The inductive analysis was undertaken in a number of phases. The first was descriptive in nature identifying broad activity phases, events of interest and highlighting broad areas of difference related to the conceptual framework. During this, extensive descriptive and analytical notes were made. Numerous processes such as ‘computing’ and ‘hypothesising’ were ultimately omitted, as there were no substantive differences in how groups used them and did little to address the research question. Nine areas in which differences did appear fell into three definable sets as listed below.

Set 1: Knowledge Differences

A. Knowledge in the Structures Unit
B. Knowledge During Problem Solving
C. Knowledge within the Solution

Set 2: Process Differences

D. Overall Process
E. Management of the Problem Solving Process
F. Process Engagement

Set 3: Social & Extrinsic Differences

G. Group Tension
H. Effects of the Competitive Dynamic
I. Study Effects

At this early stage in the analysis, these areas were regarded as broad areas within which key differences appeared to lie and arose from the manual synthesis of extensive analytical memos and descriptions. Although listed herein discretely to facilitate focused questioning of the data set, it should be recognised that these are highly interrelated and interdependent.

The following analytical stage involved specifically identifying the points of difference within each of the nine areas. Executed as an iterative process, this proved to be both demanding and time consuming not least because, unlike textual or transcript data, the raw digital wave is not searchable. Initial coding names and definitions were established from the data and notes and then applied across all of the verbal data for each group before being reviewed. The aim of the reviewing process was to ascertain the extent to which the coding names and definitions accurately reflected the differences realised within the data. In most instances, they failed to do this in their initial form and were subjected to several rounds of definitional refinement as the understanding of the context and layers of discourse around each theme of interest developed.

The following sections describe the resultant thematic codes, their evidential basis and detail the development of the associated conceptual structures and definitions subsequently explored throughout the sample as whole.

It is important to acknowledge that the nature of differences that were found meant that the analysis drew mainly from evidence within the audio data.

6.3. Set 1: Knowledge Differences

The following section will describe and evidence specific differences found in three successive stages of the task: objective knowledge from the structures unit, in-task knowledge during problem solving activity and embedded knowledge within the physical solution. Of importance to this, most notably in the second stage, is the central tenet of Dewey’s false dichotomy and notion that discretely separating knowledge from process, in many cases, is simply not possible. At some level, and some contexts, the ontological distinctions break down completely. Because of this, the basis upon which comparisons were made at each stage will be defined and clarified beforehand. Overall, comparing knowledge differences between the two groups at these key stages highlighted differences in visualisation, use of task and conceptual/principles knowledge and ultimately in procedural-tacit knowledge.

6.3.1. Attainment in Structures Unit

Structures unit results for each group are shown in Table 6.5. ‘Tension & Compression’ involved physically testing and selecting appropriate materials under each condition; ‘Triangulation’ involved physically testing the effects of triangulation in frames and ‘Turning Moments’ required the magnitude of the moment at different distances from the fulcrum to be depicted on a diagram after a teacher demonstration.

Attainment of Groups 5 and 7 in Core Areas		
	Group 5 Score (s.d.)	**Group 7** Score (s.d.)
Overall Unit (all questions)	93% (1.5)	75% (4.11)
Core Area 1: Tension & Compression	100% (0.00)	85% (1.00)
Core Area 2: Triangulation	92% (0.50)	100% (0.00)
Core Area 3: Turning Moments	75% (1.00)	50% (2.31)
Average of Core Areas	89%	78%

Table 6.5

Group 5 scored 93% in the structures unit as a whole performing to a similarly high level in all three core areas of the structures unit. This was the only group in Class 2 to score significantly above the overall class performance of 79.35% and the comparatively low standard deviation of 1.5 suggests a degree of similarity in understanding between individual members. Broadly in line with the class average, Group 7 scored 75% in the structures unit; however, the larger standard deviation of 4.11 suggests members understanding was more varied than with Group 5. Here, the lower attainment in ‘Turning Moments’ was because one group member got the magnitudes in the wrong order and group members failed to answer some of the questions.

Both overall unit scores were high, but the average attainment for Group 5 in the three core areas was 11% higher than Group 7. Given that elements of this difference arose from a failure to provide answers, it is unclear if this equates to a lesser understanding.

6.3.2. Knowledge During Problem Solving

Though knowledge during this stage was embedded within most or all of the processes pupils engaged with, ‘Visualisations’ and ‘Verbalised Knowledge’ were two areas identified in which differences lay. In the context of this study, visualisations are analogous to ideas and according to Halfin (1978), involve drawing on all the senses to construct a mental representation of a phenomena, problem, opportunity, element, system and so forth. The term ‘verbalised knowledge’ refers to instances where pupils verbally draw upon personal, task or technological knowledge in the course of problem solving. This was successfully defined and coded for whilst the former was not.

6.3.3. Knowledge as Successively Constructed Visualisations

Visualisations and ideas were evident with notable frequency with each group estimated to verbalise in the region of 160-200 across both sessions. The continuous nature of this was reflected in all of the structured observations made of each group (*see* CD-Rom). Such visualisations are significant in that they encapsulate the pupils’ knowledge of the developing solution, however, the contextual complexity and multifarious forms in which these occurred was such that establishing a definition to consistently code for differences across the data was not possible. Ideas ranged from large, more discrete visualisations about what could be done, through to rapid heuristic-type suggestions, especially during the construction phase, and virtually all possible variations between.

It was also noted that both groups frequently made use of ad-hoc modelling to both think through and communicate visualisations (Figure 6.4). This strongly reflected the concept of ‘thinking with things’ identified in the Situated Cognition paradigm of problem solving (*see* Chapter 2). Group 5 also employed a greater number of questions to prompt idea generation than Group 7 did (n=23 vs. n=4).

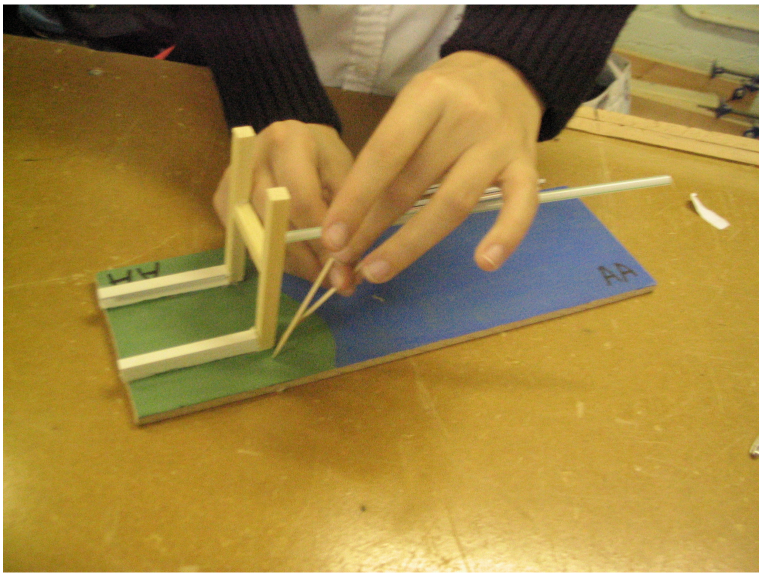


Figure 6.4 – Example of Ad-Hoc Modelling to Communicate Ideas

Though differences in visualisation were thought to exist between groups, the nature of the data and the subsequent lack of a robust coding definition meant that reporting on this is out with the scope of this study.

6.3.4. Visualisations in Symbolic Form

One key point at which pupils ideas were captured was during the sketching phase. The sketching phase was utilised effectively by Group 5 who were able to collectively reflect upon and refine what was being drawn.

6.3.5. Verbalised Knowledge

Here, phrases within group discourse that revealed dimensions of 'personal' and 'task' knowledge, as well as knowledge of principles/concepts were coded for. As defined within the conceptual framework, task knowledge relates to the problem frame, personal knowledge is prior knowledge the pupil brings from other areas, and knowledge of principles and concepts relates to the theoretical knowledge associated with structures and cantilevers. Occurrences of these within the group discourse were significantly less than was expected. The combined duration of verbalised knowledge for Group 5 accounted for around 4% of the total time spent on the task, whilst this totalled around 2% for Group 7. Despite this, differences between groups were noted in the latter two. Most notably, Group 5 verbalised significantly more knowledge associated with structures and cantilevers that Group 7. This was true for both instances as part of and out with discussion with the teacher. Group 5 demonstrated a marginally greater uncertainty of task knowledge.

In NVivo, nine codes were defined to account for the three forms of knowledge. These are described below in Table 6.6. Codes were defined in terms of incorrect/unsure to reflect the context in which they were verbalised (e.g. '*Triangulation makes it weaker*' or '*I don't think triangulation makes it stronger*').

Little difference was seen in either personal knowledge (Group 5: 10s and Group 7: 8s or task knowledge during construction (Group 5: 34s and Group 7: 31s). Additionally, no instances were coded of incorrect technological knowledge in discussion with the teacher. Tables 6.7 and 6.8 show the nodes in which differences did occur for task knowledge and knowledge of concepts & principles.

Coding Nodes for Verbalised Knowledge	
Node	**Description**
Personal Knowledge	This is defined as: *Any instance where pupils verbalise prior knowledge from out with the realm of the task or classroom.*
Task Knowledge	This is defined as: *Any instance where pupils verbalise knowledge relating to the rules or requirements of the task.* 4 nodes under this definition account for occurrences that were prior to construction, during construction, correct, incorrect/unsure.
Technological Knowledge	This is defined as: *Any instance where pupils verbalise knowledge relating to the underlying concepts and principles associated with cantilever structures.* 4 nodes under this definition account for occurrences that were as part of discussion with the teacher, out with discussion with the teacher, correct, incorrect/unsure.

Table 6.6

Of the instances of uncertain or incorrect task knowledge seen with Group 5, many of these stemmed from the same group member through questioning of whether or not a certain suggestion was allowed within the task. Although this related directly to the problem frame described in Chapter 4, it may have been a cautious disposition, rather than a lack of knowledge. Prior to construction, task knowledge was correctly drawn upon in assessing the legality of ideas.

Task Knowledge (Groups 5 & 7)			
	During Construction (Incorrect-Unsure)	**Prior to Construction (Correct)**	**Prior to Construction (Incorrect-Unsure)**
Group 5 (Whole Task)	n=6, 18s	n=3, 1m10s	n=1, 1s
Group 7 (Whole Task)	n=2, 2s	n=4, 8s	n=4, 11s

Table 6.7

Knowledge of Concepts & Principles (Groups 5 & 7)			
	With Teacher (Correct)	**Independent (Correct)**	**Independent (Incorrect-Unsure)**
Group 5 (Whole Task)	n=9, 27s	n=8, 31s	n=1, 2s
Group 7 (Whole Task)	n=4, 16s	n=6, 16s	n=4, 11s

Table 6.8

In the case of both groups, correct use of knowledge of concepts and principles in discussion with the teacher was almost always instigated and mediated by teacher questioning. It is unclear whether such knowledge would have been verbalised without such intervention. However, more significant differences were observed in discourse without the teacher present.

Firstly, Group 5 verbalised knowledge of concepts and principles to a greater extent than Group 7. Often, these instances were embedded within a reflective process as illustrated in Excerpt 1:

Excerpt 1

"It's not gonni work because its in compression and straws bend.."

(Group 5, S=9, 2.30-2.35)

Secondly, 3 of the 4 instances of incorrect knowledge coded for Group 7 appear relate to the structural deficits in the final solution (Group 7, S=3, 3.34-3.37; S=3, 3.38-3.39; S=16, 3.26-3.30). The first of these is shown in Excerpt 2 and is a comment made about the road surface on their solution.

Excerpt 2

"Yeh, but its supposed ti be able ti bend in the middle.."

(Group 7, S=3, 3.34-3.37)

The extent of the effect these occurrences had is difficult to ascertain from the data, although the comments immediately following Excerpt 2 indicated that this understanding was held by at least two group members.

6.3.6. The Solution as Manifest Knowledge

As discussed in the conceptual framework, the final physical artefact can be regarded as the culmination of knowledge applied through a range of processes. In this sense, conceptual knowledge, procedural knowledge and knowledge of principles are implicit within it but individual pupil differences during the activity were seen to engender a range of possible forms and degrees of functional performance. Figure 6.5 shows the final solution for Group 5 and Figure 6.6 shows that of Group 7 (*also see* Appendix 15).

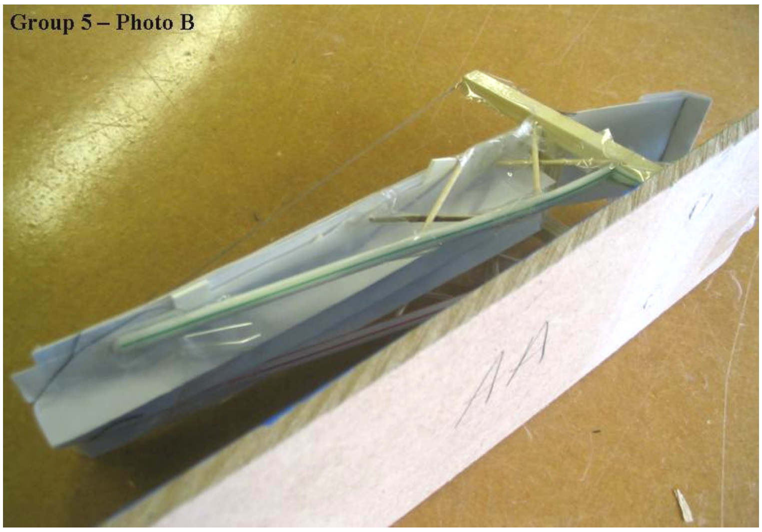


Figure 6.5 – Final Solution for Group 5

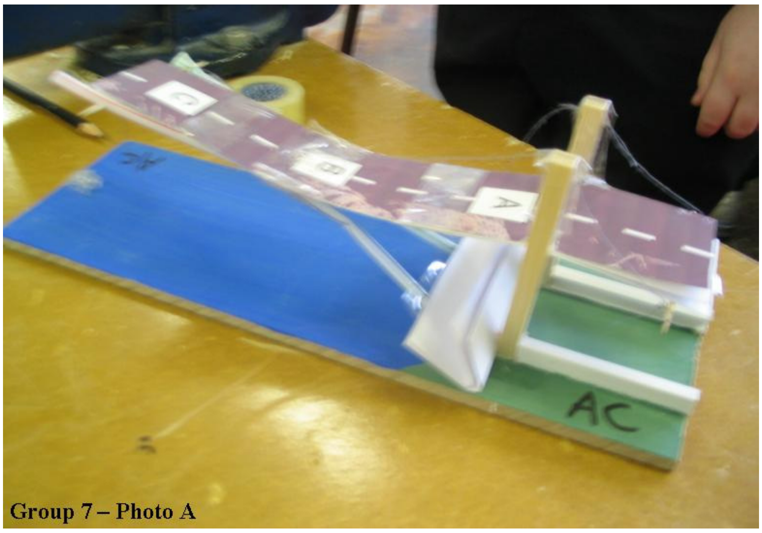


Figure 6.6 – Final Solution for Group 7

Results from the photographic analysis indicated that although 8.7% of the developments executed by Group 7 offered 'little to no functional advantage' compared with 13.8% by Group 5, the overall level of development was 36.2% greater in Group 5's solution. This analysis also revealed a series of core developments in the solutions of each group.

Figures 6.7 and 6.8 illustrate these in order of occurrence. Those shown for Group 7 pertain to the solution started at the beginning of the second session.

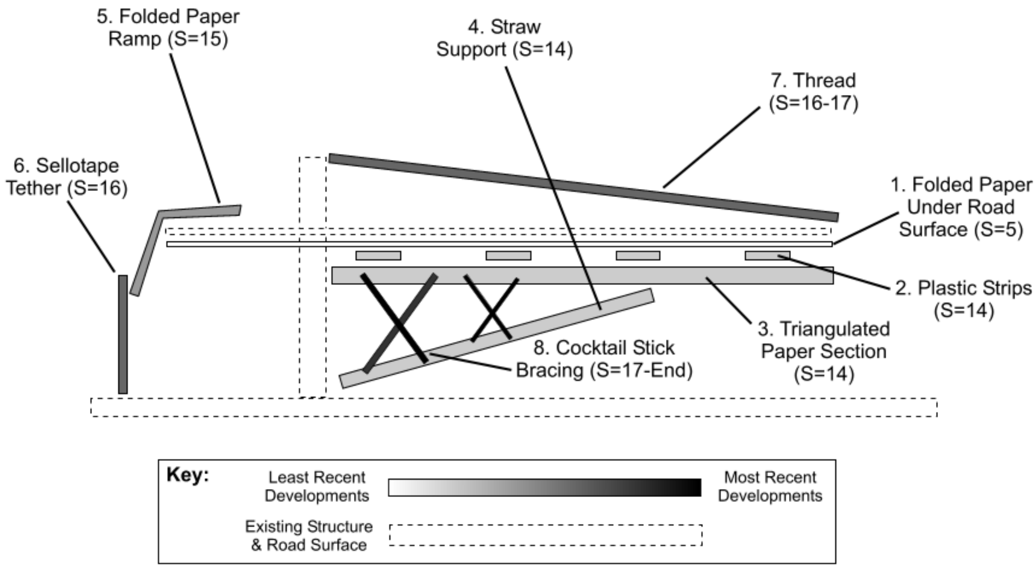


Figure 6.7 - Solution Development by Group 5

Of the eight main developments in the solution of Group 5, only 5 and 6 served no direct functional purpose within the structure. The remaining developments reflected knowledge of related concepts such as triangulation, rigidity and strength through both configuration and material choice with no evidence of misconception. Much of this is echoed in the reasons provided by the experts in the Modified Delphi (*see* CD-Rom: Face Validity Analysis). The four main themes identified were the quality of construction, the use of triangulation along the road surface and with cocktail sticks and the fact the road was made rigid with the chance of deflection significantly reduced.

In Figure 6.8, only one of the six developments identified (Folded Paper) exhibits no functional purpose in the structure. The orientation, configuration and choice of materials are similar to Group 5 insofar as each of them reflects knowledge of a related concept or principle. Indeed, Panel Member 8 in the modified Delphi described this solution as having a good conceptual basis (CD-Rom: Face Validity Analysis). However, critical differences are apparent in terms of omission and integrity; also highlighted in Delphi responses.

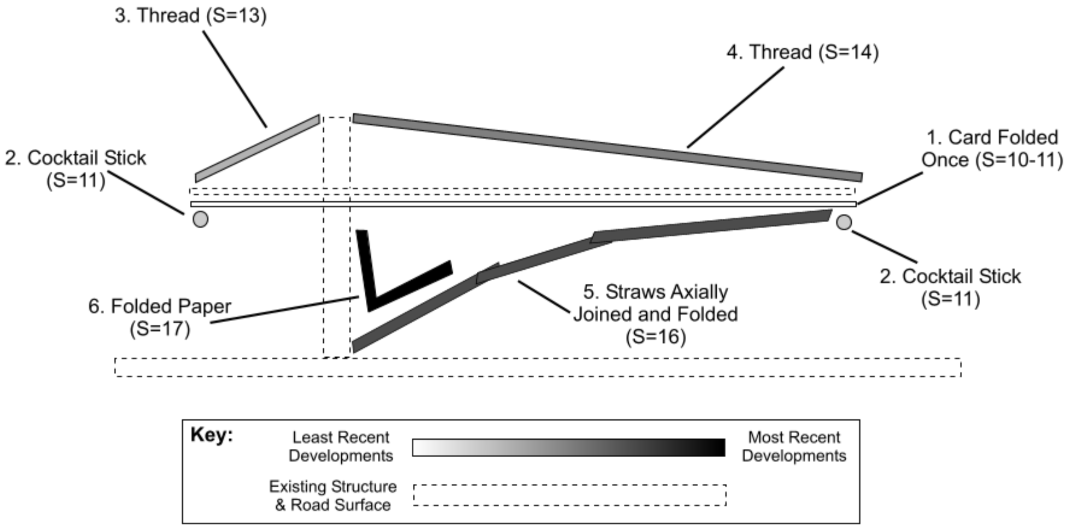


Figure 6.8 - Solution Development by Group 7

Group 7 failed to address the requirement that the road surface be rigid in order for the system to become static. The previously cited evidence from the verbal data (Group 7, S=3, 3.34-3.37; S=3, 3.38-3.39; S=16, 3.26-3.30), may suggest this was partly the result of misconception and deficient knowledge about the properties of a Cantilever. As previously shown in Table 6.5, the lowest attainment recorded for this Group in the structures unit was for turning moments and cantilevers. In one of the questionnaires (Appendix 6), the Class Teacher noted that she felt there was a lot of information imparted to pupils in a very short space of time. This could be a factor affecting the level of knowledge and understanding gained.

Figure 6.6, however, clearly shows that the solution also lacked physical integrity. In this sense, the failure by Group 7 to adequately translate concepts into a practical form of the quality seen by Group 5 indicates that a substantive difference in the respective levels of tacit-procedural knowledge, as defined within the epistemic model (*see* Chapter 2).

6.3.7. Summary of Knowledge Differences

1. Group 5 achieved higher scores in all unit areas other than triangulation.
2. Little difference was observed in the groups' use of personal knowledge.

3. Group 5 correctly voiced more explicit task knowledge prior to construction and, though instances of knowledge of concepts and principles were similar, Group 7 voiced more incorrectly than Group 5.
4. Lower build quality by Group 7 suggests lower levels of tacit-procedural knowledge, and poor material choice for strengthening road suggests an additional knowledge deficit.

6.3.8. A Framework for Exploring Knowledge Differences

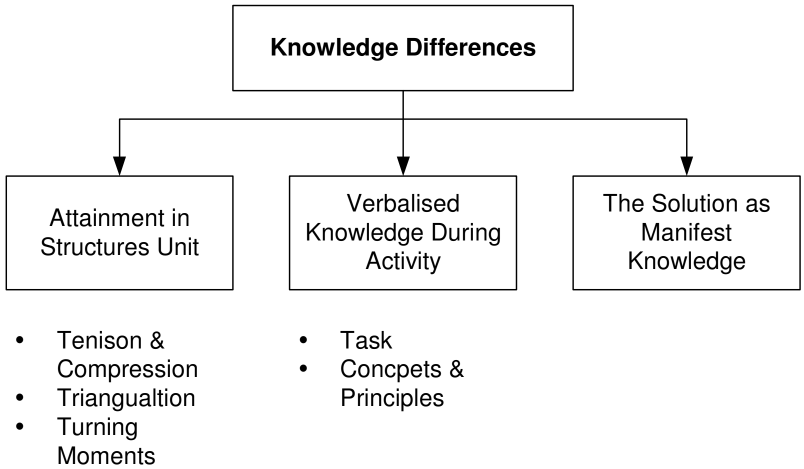


Figure 6.9 – Framework for Exploring Knowledge Differences

6.4. Set 2: Process Differences

This section establishes the specific differences that emerged within the three aforementioned areas. With regard to the global process, notable differences were identified in the pattern of solution development and in the basic phases of activity. Within the management of the problem solving process, differences were uncovered in terms of group involvement, efficiency and planning, whilst within process engagement, groups were shown to differ in terms of the reflective processes they initiate. The following section details and evidences these differences before summarising the results and presenting a resultant framework for exploring the remaining dyads.

6.4.1. Overall Problem Solving Process

This section will explore differences seen to arise in the general development of the solution and the broad phases of problem solving activity.

6.4.1.1. Pattern of Solution Development

Although both groups achieved a similar level of development by the end of the first session, and undertook the greatest level of physical development in the latter half of the second session, the path taken by Group 5 through the process was 'successive' insofar as there were no significant u-turns or changes to their physical solution. This sits in contrast to that of Group 7. Figure 6.10 depicts the cumulative development of each physical solution. On the sample number axis, 'E' represents data collected at the end of a period long session; the vertical line delimits these sessions.

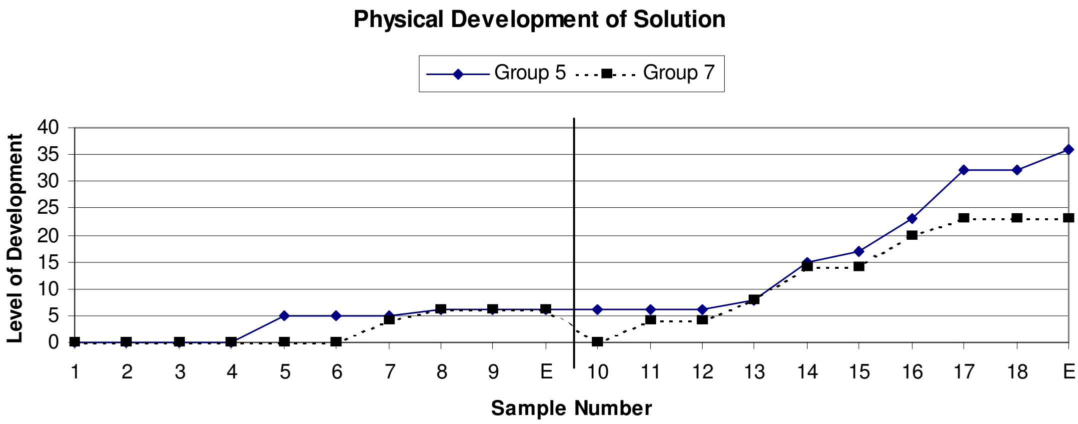


Figure 6.10 – Cumulative Development of Solution (Group 5 & 7)

Critically, the graph shows that Group 7 stripped their solution down entirely and started from scratch at the beginning of the second session, moving from a development level of six back to zero. Along with Groups 6, 11 and 13, they were one of four in the sample who removed or re-built significant sections of their solution.

The conversation in Excerpt 3 held with the teacher towards the end of Session 1 confirms that the pupils are unhappy with the solution in its current form and that taking it apart may be an option:

<u>**Excerpt 3**</u>

Teacher: "Right, let's have a wee look."

Pupil 1: "Miss, we've finished, d'yi like it?"

Pupil 2: "Yeh.."

Pupil 3: "D'yi-like it?"

Teacher: "Right, how would you improve it?"

Pupil 2: "A don't know.."

Pupil 1: "Am just about ti… fix our idea, look..look..look…look.."

Pupil 4: "..how a'd improve it… take the fill-hing apart.."

(Group 7, S=9, 2.14-2.30)

Following this, Group 7 members began removing/breaking parts (S=9, 3.33-3.52) before initiating a new phase of idea generation at the start of S=10.

6.4.1.2. Activity Phases

This task was recognised as having two broad activity phases delineated by the onset of construction activity. The former of these phases, prior to construction, is conceptual in which groups familiarise themselves with the problem, available resources and begin to generate some initial ideas.

Verbal data indicated that Group 5 began construction 12 minutes into the task, spending 60% longer in this conceptual phase than Group 7, who began after only 4m45s (confirmed by observations recorded during S=3, Appendix 11). During this phase, Group 7 made an attempt to begin construction after just 2m30s (S=1) but were unable to without scissors or tape.

After Group 5 read the task instructions aloud (S=1, 0.49-1.49), the verbal data also revealed that they undertook discrete exploration of the materials available (S=1, 1.49-2.12) which involved physically testing and comparing them. This was confirmed during the observation (Appendix 11). Group 7 did not engage in this exploratory phase here but rather did so intermittently throughout the construction phase. Although out with the scope of the data set to confirm definitively, Excerpt 4 suggests that this approach may have had a narrowing influence upon the field of consideration when generating ideas at later stages:

Excerpt 4

Teacher: *(talking to pupils about cocktail sticks)* "Now you're sure you're no gonni use these for en'hin else?"

Pupil 1: "Yeh, don't think so.."

Pupil 2: "No 'cause we haven't really… we haven't even thought about them; it's always either been straws or the wee plastic bits…"

(Group 7, S=12, 0.24-0.34)

Both groups engaged in Sketching (S=2), but Group 7 only did this to satisfy the requirement for getting scissors and tape. Critically, at the end of this conceptual phase, Group 5 had established two possible ideas for a solution (S=3, 0.56-0.59), whilst Group 7 began construction without having agreed on an idea. There was a clear urgency by Group 7 to begin constructing which was reflected in the Teachers comments about the class as a whole after the first session. In response to the question: *'If you felt there was a difference in how attentive the class were, how would you describe it?'* the teacher stated:

"Pupils seemed too intent on building part of the task to be focused on designing."
(Teacher Questionnaire, Problem Solving Session 1)

For both groups, construction activity continued until the end of the allocated task time which totalled around 71 minutes.

6.4.1.3. Summary of Differences in Overall Problem Solving Processes

1. Group 5 developed the physical solution successively whilst Group 7 re-started at the beginning of the second session.
2. Group 5 spent 60% in the conceptual phase and agreed on starting ideas where Group 7 did not.

6.4.2. Management During Problem Solving Activity

This constitutes one of the major emergent themes and relates to the process of 'Managing' identified within the Conceptual Framework. Despite it being linked to events captured by other data sources, by its very nature, it is embedded almost exclusively within the verbal interactions of the groups. Through the iterative analysis, a number of management features were identified within the modus operandi of both groups. Comparatively, these were either found to be present, missing or manifest in different ways such that the overall approach of Group 5 was characteristically more positive and in contrast to a more negative style observed with Group 7.

The emergent structure of the overall management process was defined hierarchically. The three sub-themes of 'Group Involvement', 'Increasing Efficiency' and 'Planning' were found to be central to group differences.

6.4.2.1. Management: Group Involvement

Within the NVivo software package, three nodes were developed to account for evidence of group involvement. Details of these are given below in Table 6.9.

Coding Nodes for Group Involvement	
Node	**Description**
Fragmented Vision	Classified as a negative characteristic of group involvement, this is defined as: 1. *Evidence of disagreement in the direction the problem solving activity should take.* 2. *The group pursuing more than one path through the problem, either deliberately or in error.*
Poor	Classified as a negative characteristic of group involvement, this is defined as: *Any instance that shows a group member, their actions or ideas being unjustly excluded in some way from the problem solving process.*
Role/Task Allocation/Adoption	Classified as a positive characteristic of group involvement, this is defined as: 1. *Instances where group members allocate roles or tasks to others.* 2. *Instances where group members take on roles or tasks.*

Table 6.9

It is noteworthy that the node ‘Good’ has been excluded from this sub-theme while the node ‘Poor’ has been retained. This reflects the nature of the verbal interactions by group members relative to the construct of group involvement. It was possible to identify a broad range of evidence to substantiate poor group involvement but, with the exception of instances of ‘Role/Task Allocation/Adoption’, good group involvement was largely implicit within the style of interaction between group members. Considered holistically, group involvement could be regarded as good when it is largely absent of explicit instances that make it poor.

6.4.2.2. Overview of Group Involvement

In considering the overall nature of group involvement between each case, Group 5 engaged in considerably more positive traits, whilst Group 7 engaged in considerably more negative. In many respects, the groups almost mirror each other. The total number of instances and durations coded for each session, and the task as a whole, are given below in Table 6.10. ‘Good Group Involvement’ draws upon the role/task allocation node and ‘Poor Group Involvement’ draws on the remaining two nodes.

Overview of Group Involvement (Groups 5 & 7)		
	Group Involvement (Good)	**Group Involvement (Poor)**
Group 5 (Whole Task)	n=32, 2m18s	n=2, 21s
Group 5 (Session 1)	n=17, 1m27s	n=2, 21s
Group 5 (Session 2)	n=15, 51s	n=0, 0s
Group 7 (Whole Task)	n=11, 25s	n=35, 2m17s
Group 7 (Session 1)	n=8, 19s	n=26, 1m48s
Group 7 (Session 2)	n=3, 6s	n=9, 29s

Table 6.10

In comparing the data for each session in Table 6.10, it is also clear that the positive characteristics of Group 5 are more evenly distributed between each session than are the negative characteristics of Group 7 which, following a discussion with the Teacher at the start of the second session (S=10, 0.35-1.29), were seen to decrease. A more detailed view of exactly how these are distributed throughout each session can be found in Figures 3 & 4, Appendix 21. The following sections will further detail and discuss group differences within these positive and negative traits.

6.4.2.3. Positive Traits: Roles & Tasks

The use of role allocation and adoption features heavily in the activity of Group 5 at the start of key tasks such as sketching (S=2, 1.46), as well as at points where members are not directly engaged in construction (informing also on ‘Efficiency’). In total, they allocated or adopted tasks and roles 31 times during the whole activity in comparison to just 11 instances within Group 7. Differences, however, were not confined to frequency but extended also to the reasons for instigation. Both groups took on or adopted tasks to help other group members, (e.g. Group 5, S=16, 3.33-3.38; Group 7, S=3, 0.37-0.41); both allocated tasks based upon the skills a member was perceived to have (Group 5, S=2, 1.47-1.49; Group 7, S=2, 2.03-2.06); and in one instance with Group 7, a task was adopted by one group member to prevent another executing it incorrectly (S=16, 2.11-2.13). Group 5, however, were seen to move beyond these largely pragmatic reasons for allocation and adoption. Firstly, group members were given the option to 'buy into' tasks by asking if anyone had a preference for what they wanted to do (e.g. S=4, 0.26). Moreover, Excerpts 5 and 6 demonstrate mediated allocation and adoption based upon the more considered rationales of ownership and fairness. This did not happen in Group 7.

Excerpt 5: Idea Ownership (Sketching)

Pupil ?: "You can't draw on them.."

Pupil 1: "You draw Chloe, a can't draw.."

Pupil 2: "I know a can't draw on them, that's why am doin' them; no, 'cause you, you had the ideas… 'cause you had…"

Pupil ?: "(unclear)"

Pupil 3: "Just draw your own ideas, right, you can share with mine right…. Right, you draw the thread one, I'll do the straw thing…"

(Group 5, S=2, 1.46-1.59)

Excerpt 6: Fairness

"Right, I'll cut one leg and you can cut the other… there you are, you can cut the rest."

(Group 5, S=4, 2.04-2.11)

Whilst the aforementioned approaches constitute positive aspects of process management, the negative aspects appeared to be as or more significant.

6.4.2.4. Negative Trait: Poor Group Involvement

In light of the fact that Group 5 engaged so minimally in poor managerial traits, this section will draw more heavily upon data from Group 7.

Both Table 6.10 and the process distribution plots (Appendix 21) show that, for Group 7, instances of negative involvement are more concentrated to the early stages of activity (S=1 > S=6), which was dominated on a number of levels by one group member. Additionally over this period, there were numerous instances where pupils' suggestions were readily dismissed; ideas were sometimes poorly communicated which lead to a growing level of disenfranchisement for some pupils and ultimately, a fragmented group vision. By contrast, the views of pupils in Group 5 were almost always listened to and discussed with little to no evidence of factions and differences in the vision of what the group felt they should do.

6.4.2.5. Poor Group Involvement: Dominating & Dismissing

The previously highlighted eagerness of Group 7 to begin construction, was reflected also in a lack of communication about ideas. Up until the point where this group first began physically modifying materials (S=1, 2.30), there were 11 ideas/visualisations tabled about what could be done to solve the problem. All but two of these came from the same group member who made clear his attempt to begin construction as soon as possible. This was evident to the extent that in one instance, no attempt whatsoever was even made to describe or discuss an idea with the rest of the group before attempting to construct it. Excerpt 7 shows how rapidly this pupil's focus shifts from the idea to the problem of construction with no attempt to communicate what it is:

> **Excerpt 7**
> "(Loud Inhalation) Watch ma brilliant idea..a need scissors, are you allowed scissors?"
> (Group 7, S=1, 1.36-1.41)

In addition to the domination by this one group member, there is evidence that suggestions made by other group members were ignored or dismissed. Excerpt 8 details one of the suggestions made by a different group member and shows that it was initially ignored and then dismissed by the group altogether in the absence of any clear reason or discussion:

> **Excerpt 8**
> **Pupil 1:** "We could do it that way…"
> (Pupils continue discussion without acknowledgement)
> **Pupil 1:** "You could do that.."
> **Pupil 2:** "Shut up, how-I we gonni dae that?"
> **Pupil 1:** "Well you're allowed glue, and you're allowed scissors.."
> **Several group members:** "Shut-up!"
> (Group 7, S=1, 2.07-2.28)

Notably, instances of input from this pupil being abruptly dismissed were found at other points throughout the activity (e.g. S=11 & S=17) with no substantive reason for this evident within the data. Similarly, two instances were coded for Group 5 in which one group member felt they were being ignored. Excerpt 9 follows a conversation about an idea that did not work as planned:

Excerpt 9
Pupil 1: "..but when a say cut somethin' everybody just (unclear over talk).."
Pupil 2: "shut-up Chloe… that's whit everybody says…"
(Group 5, S=5, 1.18-1.25)

Excerpt 10 followed the same group member (Pupil 1) announcing that they had a good idea to the group at a later point in the activity:

Excerpt 10
Pupil 2: "Chloe, Chloe… shhhhhh…"
Pupil 1: "You're not even listenin' to me.."
Pupil 3: "Wait a minute, wait a minute…"
Pupil 1: "Yeh, but a said that a had some-n ti say, right, and everybody just keep talkin' and nobody listens to me.."
Pupil 2: "Because we're doin' sut'm this ve-second, so…"
(Group 5, S=9, 1.32-1.46)

In contrast to similar instances with Group 7, a reason is clearly given as to why members may not have been listening and, immediately following this excerpt; Pupil 1 was given the opportunity to table her idea. Interestingly, this appears to happen to a pupil in the same situation in each group, although such instances are far more prevalent with Group 7.

6.4.2.6. Negative Trait: Fragmented Vision

It would appear that, for Group 7, the lack of balanced participation, dismissal and limited considered discussion of ideas lead to explicit divides within the group. Excerpt 7 immediately preceded initial attempts by Group 7 at construction, which, unlike Group 5, began without any group decision or consensus about what was to be done. In Group 7, towards the end of S=1, two group members voiced that they did not know what was happening; a concern that continued through the following conversation in Excerpt 11:

<u>Excerpt 11</u>

Pupil 1: "Whit the hell are yous up-ti?"

Pupil 2: "Move you"

Pupil 4: "No idea"

Pupil 2: "You're allowed-ti say hell are-yi no man…?"

Pupil ?: "Helli-yeh"

Pupil 2: "Hellilouya" (slight laughter)

Pupil 3: "Right so we gonni..(unclear) and do that.."

Pupil 1: "How-e yous up-ti?" [What are you up to?]

Pupil 2: "Jist… I know whit he's finking of.."

Pupil 4: "I don't have a clue whit yis are 'hinkin'-aw"

Pupil 3: "Neither dae-ah"

(Group 7, S=2, 0.15-0.33)

This conversation reflected a growing sense of disunity in Group 7 that was not apparent within Group 5. This was also apparent in a discussion between the group and the teacher at the start of the second session in which she encouraged the group to work more as a team, to let group members know about ideas and discuss them more (Group 7, S=10, 0.36-1.29). Moreover, it is reflected in the number of instances of fragmented vision. In most cases, fragmented vision was manifest on a 'micro-level' through disagreement over things such as the time that should be spent to make the solution look neat (S=12, 1.18-1.34); however, there was evidence within the activity of Group 7 showing that unity of vision broke down completely. In the early stages of construction, two group members decided to begin developing a separate solution to the problem (S=3, 2.52). Although this did not persist, it was indicative of the underlying fragmentation within the group.

6.4.2.7. Management: Increasing Efficiency

Within the NVivo software, one node was defined to account for any evidence of groups' explicit attempts to increase the efficiency of the process in some way. This was considered as a positive management trait. 'Decreasing Efficiency' was excluded for conceptually similar reasons to those associated with the exclusion of 'Good Involvement'. Coding for instances of 'decreasing efficiency' was simply not possible as almost anything could be attributed to this and only ever as a by-product as there was no evidence of this as an explicit, intentional behaviour within any group. Subsequently, a group can be seen to encourage increased efficiency through explicit instances of such and attempts to code for the opposite was recognised to assume an unsubstantiated dichotomy.

As previously shown in Figure 6.10, both groups exhibited a similar trend in the development of their physical solution using all of the time allocated and undertaking the greatest increase in development in the latter stages. Thus, neither group is seen to be holistically more efficient than the other. The evidence coded within the activity, however, suggests that within this, Group 5 undertook more attempts to try and increase the efficiency that Group 7 did, even if this failed to have a noticeable effect on the global process. Table 6.11 lists the coding counts and durations and shows that Group 5 initiated more than six times as many attempts to increase the efficiency of the group's activity as Group 7 did. Attempts to increase efficiency did not generally feature within the activity of Group 7.

Overview of 'Increasing Efficiency' (Groups 5 & 7)	
	Increasing Efficiency
Group 5 (Whole Task)	n=25, 1m11s
Group 5 (Session 1)	n=11, 28s
Group 5 (Session 2)	n=14, 43s
Group 7 (Whole Task)	n=4, 10s
Group 7 (Session 1)	n=3, 9s
Group 7 (Session 2)	n=1, 1s

Table 6.11

Comparing the groups, there were both similarities and differences in the nature of these instances. Of the four instances coded for Group 7, three were in the form of simple prompts to 'hurry up' (S=5, 3.02-3.04; S=6, 2.22-2.23; S=11, 1.34-1.35) and the fourth, shown in Excerpt 12, questions how long a given idea will take:

> **<u>Excerpt 12</u>**
> **Pupil 1:** "Aye, right, so how much are we gonni get done today Scott?"
> (laughter)
> **Pupil 2:** "Well, yous just carry on and al just sit and do this.."
> (Group 7, S=3, 1.33-1.40)

As previously seen with 'Role/Task Allocation/Adoption', Group 5 exhibited similar characteristics to Group 7 when increasing efficiency, but also demonstrated additional and more complex approaches. They attempted to increase pace using the same basic prompts as seen with Group 7 (e.g. S=4, 0.49-0.52; S=9, 0.48-0.50; S=12. 0.54-0.57), some of which were personally directed and some of which were impersonal and encouraged the group as a whole to just keep working (e.g. S=18, 2.11-2.13). Further to this, however, Group 5 attempted to increase efficiency by altering the structure of activity and initiated tasks in parallel. Excerpts 13 to 15 exemplify this and it was not observed in the activity of Group 7.

Excerpt 13
"Well, while yous are doin' that, we can work on the straws.."
(Group 5, S=7, 3.34-3.36)

Excerpt 14
"See instead-e all-e-us watchin', we could all be doin' su-hum instead-o watchin' Leanne.."
(Group 5, S=11, 0.29-0.34)

Excerpt 15
"..Someone else doin' suttin, let's see what else needs…"
(Group 5, S=4, 0.49-0.52)

6.4.2.8. Management: Planning

Within the NVivo software, two nodes were defined to account for aspects of planning. These are detailed below in Table 6.12.

Within this sub-theme, nodes again were defined to reflect the scope of the verbal data. The nature of the verbal data meant that it was not possible to reliably determine if a given instance of 'planning', as encompassed by the first node, was poor. The effects of it may not be realised until much later within the activity at which point, the content of pupils' discourse rarely allowed it to be attributed back to any one specific event. Indeed, planning understood by the pupils to be good and sufficient at the time may prove to have been poor in retrospect. Because of this, attempts to do things such as sequence and prioritise are regarded as positive and coded for at the first node.

Occurrences during the activity that could have been avoided through better planning were considered negative and coded for at the second node. The aforementioned reasons mean that these do not identify the poor planning *per se*, but rather the results thereof.

Coding Nodes for Planning	
Node	**Description**
Good Planning	This is defined as accounting for evidence of: 1. *Determining use of/amount of materials/resources.* 2. *Sequencing, Ordering or Prioritising.* 3. *Identification of Global Requirements (identifying the areas in which an idea is required)* 4. *Working through how an idea should be practically executed.*
Result of Poor Planning	Classified as a negative characteristic of planning, this is defined as: *Any occurrence where something is realised to be impeded, prevented or negatively altered by previous, sometimes unrelated, actions.*

Table 6.12

6.4.2.9. Overview of Planning

Both groups made use of a range of forms of planning while only Group 7 had evidence of events that could have been avoided through better planning. Below, Table 6.13 shows that Group 5 spent over three times as long as Group 7 did engaging in planning processes. Interestingly, the distribution indicates that this was more evident for Group 5 during the second session and for Group 7 during the first.

Overview of 'Planning' (Groups 5 & 7)		
	Planning	**Result of Poor Planning**
Group 5 (Whole Task)	n=56, 8m17s	n=0, 0s
Group 5 (Session 1)	n=27, 3m27s	n=0, 0s
Group 5 (Session 2)	n=29, 4m50s	n=0, 0s
Group 7 (Whole Task)	n=98, 2m23s	n=10, 0m56s
Group 7 (Session 1)	n=22, 1m34s	n=7, 0m38s
Group 7 (Session 2)	n=76, 49s	n=3, 18s

Table 6.13

Though not co-relational, the patterns of planning and the effects of poor planning for both groups are consistent with the previously established development patterns of each solution. Group 5 undertook successive development with the majority of construction in the second session, but the poor planning may have been a more significant factor for Group 7. Results of poor planning by Group 7 were far less prominent after both 're-starting' their solution and discussing better communicating and 'thinking through' of ideas with the teacher. Moreover, this drop in instances of poor planning was mirrored by a 73% drop in instances of poor group involvement, as shown in Table 6.10 (Page 194).

6.4.2.10. Effects of Poor or Insufficient Planning

Though limited, evidence of the effects of poor planning in the activity of Group 7 related mainly to poor communication, and partly to a lack of foresight. The poor communication related to tasks and how different parts of the solution were to be developed. Not only did the group fail to sketch all the relevant ideas (Group 7, S=8, 1.27-1.33), but also realised that two group members spent a significant period of time unintentionally drawing the same idea (Group 7, S=2, 3.19-3.26). With regard to the solution, there were instances where pupils sellotaped the wrong part in place (Group 7, S=17, 1.26-1.40) and glued parts in the wrong order (Group 7, S=5, 1.28-1.30 and 1.48-1.56). As well as communication related deficits, Excerpt 16 again demonstrates the group's general haste in constructing and a lack of forward planning which was likely to affect possible developments:

Excerpt 16

Pupil(s): (unclear)

Pupil 1: "don't tell me you've cut up every single straw…"

Pupil 2: "yip.."

Pupil 3: "..yeh, we've cut every single straw.."

Pupil 1: "Why?"

Pupil 4: (unclear)

Pupil 1: "That's it ruined noo-a had a brilliant idea.."

(Group 7, S=4, 1.29-1.40)

6.4.2.11. Planning

As previously stated, there is evidence that both groups engaged in the same forms of planning. Both considered the availability of materials for, and matching of materials to, given ideas (e.g. Group 5, S=5, 3.38-3.48; Group 7, S=4, 2.20-2.34; Group 7, S=12, 1.53-2.00). This involved processes such as counting the number of cocktail sticks left and comparing it to the estimated number required for a specific development. Additionally, groups identified global requirements. The term 'global requirements' was specifically utilised to reflect things that needed to be addressed prior to any specific idea or visualisation being formulated. Such instances are often brief and are exemplified for both groups in Excerpts 17 and 18.

Excerpt 17

Pupil 1: "We're gonni need-ti dae suh-m…"

Pupil 2: "..We need it a bit bigger.."

(Group 7, S=15, 0.51-0.56)

Excerpt 18

"…but look at the road….. it sticks out at the back.."

(Group 5, S=13, 1.53-1.59)

The significance of these is that they should draw attention to weaknesses in the solution and catalyse idea generation. Though the functional integrity of what was done is not relevant in this context, the weakness identified in Excerpt 18 resulted in Group 5 quickly applying a tether between the ramp and the ground as shown below in Figure 6.11.

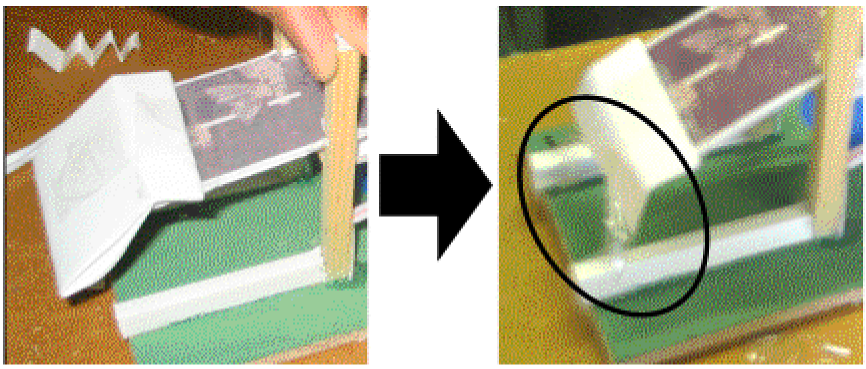


Figure 6.11 – Response to Identified Weakness by Group 5

The weakness in Excerpt 18 was voiced by the pupil whose input was often dismissed and, despite him voicing it on two subsequent occasions (Group 5, S=14, 2.48-2.56 and S=15, 0.37-0.40). Group 7, by contrast, failed to adequately address it. Given that it related to the rigidity of the road surface, a core weakness identified by the Delphi (*see* CD-Rom:

Face Validity Analysis), addressing it could have significantly improved the overall performance of the cantilever.

In regard to sequencing, both groups demonstrated evidence of knowledge about the best order in which tasks should be done and stages of a given development executed (e.g. Group 5, S=4, 2.30-2.40; Group 7, S=2, 1.54-1.56). Furthermore, Group 5 considered this concept from a different perspective when one group member asked if there was anything additional they wanted to add because they would not be able to after a certain piece had been stuck down (S=8, 1.33-1.42).

This latter example suggests a degree of forward planning or future consideration, which forms the core evidential focus of the final dimension of planning. Working through how an idea will be executed constituted a period of pro-active, rather than reactive discourse signified by assertions about what will or should be done. These conversations were typically extended and often involved the generation of new ideas, but they were only coded against the planning node when they were discussing something yet to be done. Conversations about how do things as they were being done were not coded against this node.

Evident within both Groups, these discussions could integrate thinking on materials, joining methods, placement and order and were normally proceeded by construction activity. Excerpts 19 and 20 are representative examples from each group.

> **Excerpt 19**
> "A teeny-wee, eeny-wee bit-a cardboard, right, this is the cardboard, right.. put glue on-it so that's on that, right.. then put glue on it there so it sticks down.. su't-n ti [something to] stick down, d'yi know whit a mean?"
> (Group 5, S=9, 2.10-2.20)

> **Excerpt 20**
> "But look, am thinkin' we do that, right, then that wee bit goes doon there, then the lang-wee bit goes doon there!"
> (Group 7, S=7, 3.35-3.41)

Whilst the nature of these was similar in both groups, it was more prevalent in Group 5 than in Group 7.

6.4.2.12. Summary of Process Management

1. Group 7 had more poor group involvement, was fractious and suffered from side-lining and a domineering member. Group 5 showed good group involvement through varied use of role and tasks.
2. Group 5 made more attempts than Group 7 to increase efficiency and engaged in significantly more planning.
3. Instances arising from poor planning were only coded with Group 7.

6.5. Process Engagement

This theme relates to differences identified in both the reflective turns groups engaged with and the nature of the associated reasoning. As with the Management theme, though this will inevitably affect countless aspects of the way the problem is solved, it resides wholly within the verbal data. Interestingly, Halfin (1978) does not specifically identify 'reflection' as a mental process involved in technological problem solving, rather, it is implicit within a range of sub-operations such as 'Evaluating alternate solutions' within the process of 'Designing'. Although definitional variations inevitably arise from differences in how the problem solving process is conceptualised, it is possible to identify the presence of reflective processes within all of them. Subsequently recognised here as 'retrospective' thought process, it was acknowledged that reflection could be manifest in a range of forms such as comparing, evaluating, assessing, judging, justifying, analysing and questioning. Through iterative coding, it was realised that the insightful differences did not lie in distinguishing between these aforementioned forms, but rather, in distinguishing between the extent to which reasoning was revealed. Two levels of reflection were defined: 'Declarative' and 'Analytical' and Group 5 were seen to engage more with the latter form of reflection than Group 7.

6.5.1. Reflection as a Retrospective Process

In both cases, reflection is defined as a statement made about an idea or practical development already stated or done. Firstly, this means that it is highly context dependent. Secondly, it means that recounting what was done is not considered to be reflection, and thirdly, it does not mean that reflective phrases were necessarily verbalised in the past tense; it was often the case that many of them appeared with a predictive dimension. 'Declarative' and 'Analytical' reflection are defined below.

6.5.2. Defining Declarative Reflection

This is defined as a statement about something already said or done that *does not* reveal reasoning.

Examples of this are often discrete, summative judgements such as: ‘that’s good’, ‘that’s poor’, ‘that’s too long’, ‘that’s not going to work’, and ‘that’s too tight’. Many of these are close to qualitative observations. Some statements, such as: “That’s not going to work”, may have required the pupil to engage in deeper cognitive processing in formulating this conclusion. In terms of the group discourse, this would still be coded as declarative because any deeper associated reasoning that did occur, either implicitly or explicitly, is concealed.

6.5.3. Defining Analytical Reflection

This is defined as s statement about something already said or done that *does* reveal reasoning.

Examples of this varied in nature and, again, are context dependent. In most cases, occurrences were obvious explicitly featuring the reason within the statement, sometimes delineated by syntactic separators like ‘because’. Examples are shown in Excerpts 21, 22 and 23 (Page 210).

Other, less common occurrences were when reasoning was more contextually implicit. This can be demonstrated by comparing two very similar statements, the first of which was extracted from the data and the second is hypothetical for the purposes of exemplification. Both statements are made about an idea that had been proposed and convey the notion that, in the context of what was being considered, straws were the better option. The statements are as follows:

Statement 1
“The straws would make it easier.”
(Group 5, S=17, 0.22-0.24)

Statement 2
“We need it a bit bigger…”
(Group 7, S=15, 0.54-0.56)

For the purposes of this exemplification, it is herein assumed that statement 2 relates to the use of straws. Though both are in the form of single judgements with no explicit reason present, the second would be coded as declarative and the first was coded as analytical. This is because it was not possible to determine why the pupil considered the straws to be better in the second statement, but in the first, the pupil links their choice to the level of difficulty.

Another example of this was seen when one pupil from Group 7 reflected on the axial joining of the straws under the road surface and stated: "Where that's joined, it might bend" (Group 7, S=15, 3.56.3.58). Rather than simply stating *'that's going to bend'* or *'that's not going to work'*, the statement identifies the joint as a potential cause of failure.

6.5.4. Coding Exclusions

The nature of the verbal data set is extremely complex and judgements as to whether a reflective statement was declarative, analytical or neither depends heavily upon the context in which they arise. The definitions described here allowed most of the reflective statements to be categorised but the complexity of the discourse meant that in a few instances, reflections could not be legitimately categorised. Such instances were omitted from coding.

In addition to non-conformity exclusions, accounts of what was done and reflection in the form of simple agreement were not coded either.

Within the NVivo software, six nodes were defined to account for two types of reflection at two different levels for both the conceptual and practical phases of problem solving. These are detailed in the Table 6.14.

In comparing both groups, the following sections describe Task, Declarative and Analytical Reflection, along with the associated evidential bases, in greater detail.

Coding Nodes for Reflection	
Node	**Description**
Task Reflection (Prior to Construction)	Concerned only with the constraints or requirements of the task, this is defined as: *Retrospective consideration in relation to the developing solution during the conceptual phase.*
Task Reflection (During Construction)	Concerned only with the constraints or requirements of the task, this is defined as: *Retrospective consideration in relation to the developing solution during the practical phase.*
Declarative Reflection (Prior to Construction)	Concerned with the developing solution and problem solving process, this is defined as: *Reflective statements that are close to the observable with no reasoning present during the conceptual phase.*
Declarative Reflection (During Construction)	Concerned with the developing solution and problem solving process, this is defined as: *Reflective statements that are close to the observable with no reasoning present during the practical phase.*
Analytical Reflection (Prior to Construction)	Concerned with the developing solution and problem solving process, this is defined as: *Reflective statements that move beyond the observable with reasoning present during the conceptual phase.*
Analytical Reflection (During Construction)	Concerned with the developing solution and problem solving process, this is defined as: *Reflective statements that move beyond the observable with reasoning present during the practical phase.*

Table 6.14

6.5.5. Overview of Reflective Processes

The overall coding for reflective processes showed that Group 5 and 7 verbalised a similar number of reflective processes (n=216 and n=209, respectively) although the amount of time spent reflecting was 17% greater with Group 5. The average length of each reflective phrase for this group was 2.29s compared with 1.96s for Group 7. This difference, though apparently small, is symptomatic of the different types of reflection engaged with. The inclusion of some level of reasoning in analytical reflection often results in longer statements than the summative or observational phrases associated with declarative reflection; Group 7 spent 15.4% less time than did Group 5 engaged in analytical reflection.

6.5.6. The Nature of Reflection During the Conceptual Phase

The distribution of reflective processes for each group before the commencement of construction activity is shown in Table 6.15.

Reflection Prior to Construction Commencing (Groups 5 & 7)				
	Analytical	**Declarative**	**Task**	**Total**
Group 5 (Session 1)	n=8, 26s	n=11, 14s	n=1, 3s	n=20, 43s
Group 7 (Session 1)	n=0, 0s	n=6, 10s	n=4, 12s	n=10, 22s

Table 6.15

The conceptual phase (prior to the construction) is one in which pupils familiarised themselves with the task and resources and generated some initial ideas for solving the problem. The overall level of reflection shown is concurrent with the fact that Group 5 spent 60% longer in this phase than Group 7. Having not adequately familiarised themselves with the task, Group 7 spent more time than Group 5 reflecting on whether ideas were permissible at this stage, though during construction, the opposite was observed with Group 5 engaged in task reflection for nearly three times as long as Group 7.

Prior to construction, little difference was observed in the nature of the declarative reflections of each group. They comprised such things as short assessments of whether something was good or not (e.g. Group 5, S=3, 1.10-1.11; Group 7, S=1, 1.55-1.56). Though these were essential to quality assuring ideas, suggestions and later construction, the absence of analytical reflection in the activity of Group 7 presented the starkest disparity. This could be concomitant with the lack of proper discussion and communication of ideas earlier highlighted. Excerpts 21 through 23 illustrate the type of analytical reflection that Group 5 did engage with during this phase of idea generation:

Excerpt 21

Pupil 1: "I don't know, 'cause the threads a bit..

Pupil 2: "dodgy…"

(Group 5, S=2, 0.36-0.40)

Excerpt 22

"Aye, that would be better 'cause that is stronger than a bit of thread…"

(Group 5, S=2, 0.57-1.02)

Excerpt 23

"Aye… 'cause that… 'cause li'e a s'pose [like I suppose], see as long as we, right, I'm gonni use these things, right, but as long as its comin' fae the land we could have them different lengths which is another bit-a support holdin' them up, see…"

(Group 5, S=2, 2.53-3.06)

In contrast to statements of declarative reflection, these examples reveal more of the thinking process, in turn, making it available to other pupils within the group. Although the cognition underlying the declarative reflective statement: "that's no gonni be strong" (Group 7, S=2, 0.49-0.51) may have been quite involved for the pupil, the absence of verbalised reasoning means that understanding is partially masked and there is no evidential way of knowing. Analytical reflection was thus regarded as empirical evidence of deeper, and more public engagement in reflection.

6.5.7. The Nature of Reflection During the Construction

Despite the absence of analytical reflection by Group 7 in this early stage, it was evident throughout the remaining activity. Table 6.16 shows the overall breakdown of reflective processes across both problem solving sessions.

As with reflection prior to construction, Table 6.16 shows the biggest difference during this phase to lie in the level of analytical reflection, though Group 7 made greater use of declarative reflection. These essentially form quality control mechanisms for both suggested ideas (e.g. Group 7, S=10, 0.04-0.05) and of construction (e.g. Group 7, S=12, 0.01-0.03). The same was true for Group 5.

Reflection During Construction Phase (Groups 5 & 7)				
	Analytical	**Declarative**	**Task**	**Total**
Group 5 (Whole Task)	n=75, 3m47s	n=145, 4m07s	n=7, 26s	n=227, 8m20s
Group 5 (Session 1)	n=46, 2m17s	n=76, 2m01s	n=3, 7s	n=125, 4m25s
Group 5 (Session 2)	n=29, 1m30s	n=69, 2m06s	n=4, 19s	n=102, 3m55s
Group 7 (Whole Task)	n=45, 2m10s	n=164, 4m30s	n=5, 10s	n=214, 6m50s
Group 7 (Session 1)	n=23, 1m15s	n=81, 2m16s	n=2, 5s	n=106, 3m36s
Group 7 (Session 2)	n=22, 55s	n=83, 2m14s	n=3, 5s	n=108, 3m14s

Table 6.16

The analytical reflections observed with both groups shared some common characteristics. Firstly, they were observed to occur prior to, during and after an idea was practically enacted. Secondly, they almost always had a predictive component to them or revealed a pupil's path in arriving at a level of understanding with regard to a given development. Typical examples of this are shown in Excerpts 1 and 24. In the first of these, a pupil predicts the failure of an idea based upon the forces a given material is likely to be subjected to. In the second, a pupil gains increased understanding in the midst of verbalisation.

Excerpt 1
"It's not gonni work because its in compression and straws bend.."
(Group 5, S=9, 2.30-2.35)

Excerpt 24
"no, that'll be… oh aye, 'cause that would weigh it down and it'd go inti the water.."
(Group 7, S=14, 3.35-3.38)

Though far less common, Excerpt 25 shows an instance where Group 5 employed analytical reflection in a diagnostic role and, for Group 7, Excerpt 26 illustrates an analytical reflection with its basis in just reasoning rather than with knowledge as well.

Excerpt 25

"You know what we've done? We've done that bit at the front too tight and its made it bend.."

(Group 5, S=8, 0.22-0.27)

Excerpt 26

"Aye, well if we've done one side, we should do the other side.."

(Group 7, S=6, 3.27-3.30)

All of the instances of analytical reflection revealed more of the thinking process and in this respect were seen to be similar for both groups. Both groups generally employed declarative reflections for the purposes of quality assuring and 'in-activity' evaluating. The only notable differences were the extents to which each group engaged with them.

6.5.8. Summary of Process Differences

1. Overall, Group 5 engaged in significantly more reflective processes than Group 7 did.
2. Group 5 utilised more analytical reflection prior to and during construction activity.
3. Group 7 engaged in more declarative reflection during construction.
4. Group 7 reflected more on the task prior to construction, though little overall difference was observed with this measure.

6.5.9. A Framework for Exploring Process Differences

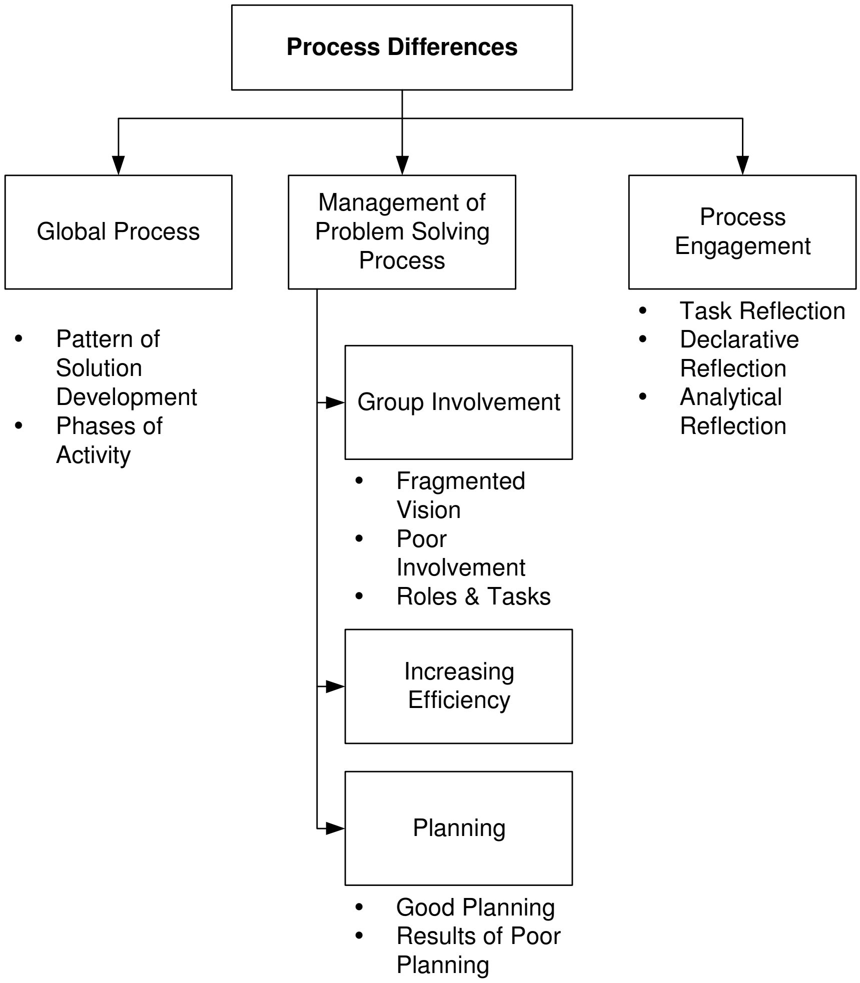


Figure 6.12 – A Framework for Exploring Process Differences

6.6. Social & Extrinsic Differences

This set of themes relates to group differences that arose due to external influences and internal group dynamics. This set differs from the previous two insofar as its themes are not conceptually implicit in the conceptual framework for technological problem solving, but nonetheless, had a direct and tangible effect upon the activity of groups. Three themes were identified in this set in the form of 'Group Tension', 'Effects of Competitive Dynamic' and 'Study Effects'. What became apparent through exploring the data was that the groups were affected by these in very different ways.

6.6.1. Group Tension

Within the NVivo software, one node was defined to account for evidence of tension between group members. Here, tension was considered a negative aspect of group activity and arose for a variety of reasons. Within the verbal data, group tension was evidenced by argumentative discourse, raised voices between pupils, exasperation and tone of voice; something not as easily conveyed through verbal transcripts. Indeed, instances of such tension between group members were more readily identifiable because the raw audio file was coded directly. The comparative analysis showed that instances of tension in Group 5 were negligible in comparison to those in Group 7, despite the fact the class teacher composed each group to minimise this (as per the Methodology: Chapter 4). Table 6.17 illustrates the magnitude of this contrast.

Overview of Group Tension	
	Tension
Group 5 (Whole Task)	n=4, 0m24s
Group 5 (Session 1)	n=4, 0m24s
Group 5 (Session 2)	n=0, 0m00s
Group 7 (Whole Task)	n=38, 2m38s
Group 7 (Session 1)	n=29, 1m40s
Group 7 (Session 2)	n=9, 58s

Table 6.17

The four counts of tension for Group 5 were both sporadic (occurring in the 7th, 20th and 35th minutes of the first session) and arose due to a group member being ignored and failure to construct a given idea satisfactorily. As opposed to arising from isolated events, the pattern of distribution for Group 7 depicts tension as a fairly continuous feature of problem solving activity, although this was less so during the second session. Figures 6.13 and 6.14 illustrate this distribution in more detail.

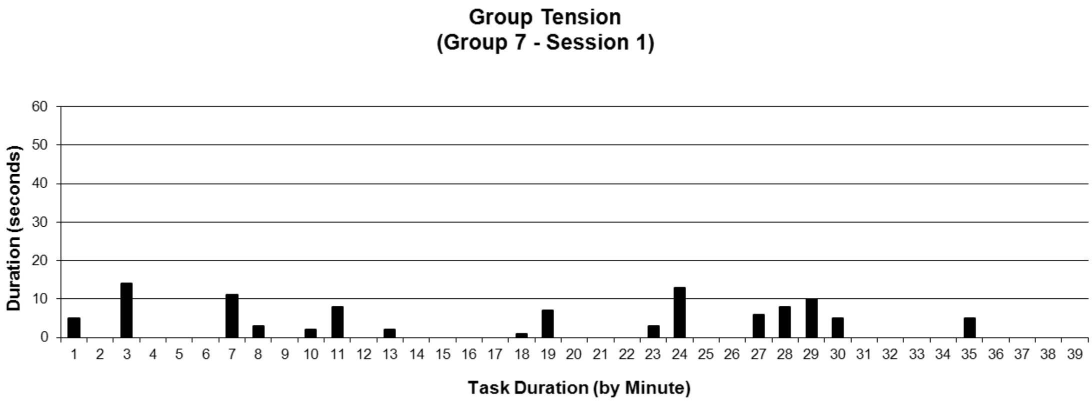


Figure 6.13 – Distribution of Instances of Group Tension (Group 7, Session 1)

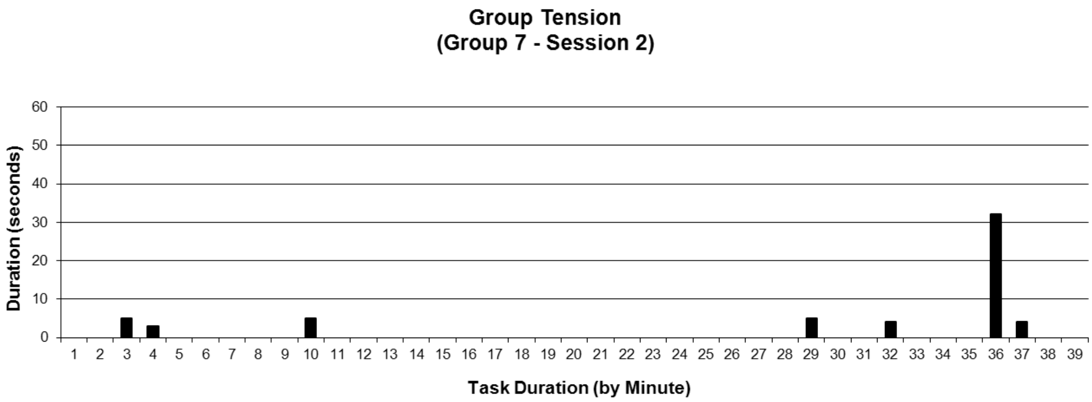


Figure 6.14 – Distribution of Instances of Group Tension (Group 7, Session 2)

As shown, there are two features of interest in the distribution. Firstly, there is a visible drop in the counts of tension in the second session compared with the first and, secondly, that 55% of these occur on the 36th minute of this session. The latter drop in tension may be a symptom of the group re-starting the solution and attempting to work more collaboratively as advised by the teacher (Group 7, S=10, 0.36-1.29). This is concordant with the previously illustrated 73% drop in negative managerial traits during this same period. As shown in Excerpt 27, the tension observed around the 36th minute related to one pupil breaking the thread support on the top of one side of the bridge (confirmed in photographic evidence for S=18 and S=End):

Excerpt 27

Pupil 1: "whit-e yi cutting' it anymare if you broke it?"

Pupil 2: "Paul, that wis good an-you went and broke it.. aaaahhhh!"

Pupil 3: "no got a chance-e sellotapin' the string in-ere noo.."

Pupil 2: "Aye it is.."

Pupil 1: "Shut up…"

Pupil 2: "You are a pure… can't even say it…. a don't care, you're a pure (expletive)"

(Group 7, S=End (Session 2), 2.01-2.30)

6.6.2. Effects of Competitive Dynamic

The competitive task dynamic was set up by the structure of the task, goals and learning environment; groups were aware that their solutions would be tested and judgements made as to the resultant performance. Within the audio data, this was seen to exert positive, negative and neutral influences upon group activity. This resulted in three corresponding nodes being defined within the NVivo software: ‘Competitive Dynamic (+)’, ‘Competitive Dynamic (-)’ and ‘Competitive Dynamic (n)’. Table 6.18 shows the results of coding to these nodes for both groups.

Effects of Competitive Dynamic (Groups 5 & 7)			
	Negative	**Positive**	**Neutral**
Group 5 (Whole Task)	n=5, 20s	n=1, 2s	n=3, 46s
Group 5 (Session 1)	n=2, 10s	n=1, 2s	n=1, 14s
Group 5 (Session 2)	n=3, 10s	n=0, 0s	n=2, 32s
Group 7 (Whole Task)	n=24, 2m49s	n=5, 7s	n=4, 30s
Group 7 (Session 1)	n=13, 1m31s	n=2, 2s	n=3, 23s
Group 7 (Session 2)	n=11, 1m18s	n=3, 5s	n=1, 7s

Table 6.18

Through the problem solving process, Group 5 was far less concerned than Group 7 with events taking place with other groups out with their own activity. This is reflected by the fact that Group 7 had 3.7 times as many events resulting from the competitive dynamic. Moreover, the most dominant category here was negative effects totalling 73% of events coded, whilst for Group 5, 33% were neutral. In the case of both groups, neutral effects were in the form of observations of the activity by other groups with no overt positive or negative bias. Examples of this are shown in Excerpts 28 and 29.

Excerpt 28

Pupil 1: “Dobie, their’s doesn’t even move..”

Pupil 2: “Does it nut…?”

Pupil 3: “Whit?”

Pupil 4: “That’ll still loose ‘cause it’s s’posed-ti be able-e move…”

(Group 7, S=16, 3.22-3.30)

Excerpt 29

Pupil 1: “Look at theirs…”

Pupil 2: “Oh, that’s cool… that’s just goin’ weeeee up the way…”

Pupil 3: “A don’t see why we can’t have it touchin’ water, everybody else can… that bridge has got wee poles in the water by the way.. see, so why can’t we put (unclear)”

(Group 5, S=16, 3.11-3.33)

The overall dispersion of effects for Group 5 was fairly even although there was a degree of clustering observed in the second half of each session with Group 7. In the first session, several factors contributed to this including interference from and with other groups (S=7, 0.07-0.12), attempting to copy other groups (S=7, 1.14-1.22) and comparing the solutions of other groups (S=8, 2.55-2.59). In the second session, it was virtually all inter-group interference, which appeared to accompany a drop in focused construction activity with solutions in fuller state of completion. These constitute negative effects and were often seen to instigate a degree of tension as illustrated in Excerpt 30.

Excerpt 30

Other Group: "They're copyin' us.."

Pupil 1: "Who, you… us!"

Pupil 2: *Raised Voice* "How-a we?"

Pupil 1: "How are we copyin'-ye?"

Pupil 3: *Raised Voice* "Whit-ye talkin' aboot…? ..yis have-ny even done any'ing…"

Other Group: (Unclear)

Pupil 3: "Make me!"

(Group 7, S=4, 0.14-0.23)

Copying and taunting between groups was the most prevalent negative effect observed. It is also noteworthy, however, that just as Group 7 exhibited more negative effects than Group 5, it also exhibited more positive effects. Examples of such instances are shown in Excerpts 31 and 32 and served to motivate the group. A similar statement occurred only once with Group 5 (S=8, 0.15-0.17).

Excerpt 31

"A 'hink we should win 'cause we've achieved the most man…"

(Group 7, S=17-18, 3.58-0.02)

Excerpt 32

"Yas, man… we're gonni win.."

(Group 7, S=11, 3.44-3.46)

6.6.3. Effects of the Study

As discussed within the Methodology Chapter, the very fact the study is taking place is likely to exert an effect upon the participants, consciously or otherwise. The class teacher, common to both these groups, reported that the class was more excited than normal and harder to settle. Overall, she reported better behaviour and that all pupils, with the exception of two, participated despite group work not being the 'norm'. (Teacher Questionnaire, Appendix 6)

Two nodes were defined within the NVivo software to account for this in regard to the researcher and the audio recorder. These nodes are defined in Table 6.19.

Coding Nodes for Study Effects	
Node	**Description**
Researcher Effects	This is defined as: *Any aspect of group activity or discourse that arises as a direct result of the researchers presence.*
Recorder Effects	This is defined as: *Any aspect of group activity or discourse that arises as a direct result of the presence of the audio recorder.*

Table 6.19

In addition to undertaking the task, pupils in all groups completed an individual profiling questionnaire allowing them to select statements that best reflected their perceptions. Tables 6.20 and 6.21 show group responses that relate to the role of the researcher and of the tape recorder.

Responses to: 'I did not like being observed by the researcher.' (Groups 5 & 7)				
	Group 5		**Group 7**	
	Session 1	**Session 2**	**Session 1**	**Session 2**
Strongly Disagree	1	2	3	4
Disagree	0	1	1	0
Unsure	0	0	0	0
Agree	2	0	0	0
Strongly Agree	0	0	0	0
Missing Data	1	1	0	0

Table 6.20

Responses to: 'I did not like being recorded by the tape machine.' (Groups 5 & 7)				
	Group 5		**Group 7**	
	Session 1	**Session 2**	**Session 1**	**Session 2**
Strongly Disagree	3	3	2	2
Disagree	0	0	0	0
Unsure	0	0	0	1
Agree	0	0	0	0
Strongly Agree	0	0	2	1
Missing Data	1	1	0	0

Table 6.21

As can be seen, Group 5 appeared to be more negatively affected by the researcher than Group 7 was in the early stages, though in both instances, this effect reduced most likely due to growing task involvement and acclimatisation effects. One member in each group felt that they should answer questions differently as a result of the researcher being there. By contrast, being recorded had a more negative effect on Group 7. There was greater variation in perceptions and, for one pupil, this negative effect continued through both problem-solving sessions. Instances coded within the audio data are reported in Table 6.22 and reflect some aspects of the perceptions shown above.

Firstly, there is little difference between the groups in terms of researcher effects, though Group 7 see a more notable drop in this during the second session. For both groups, it was the researcher arriving at their table to observe or take photographs that triggered most of the events. Group 7 did, however, discuss the fact they were not supposed to ask the researcher questions (S=3, 3.14-3.28) and did later question if the researcher was the only person allowed to hear the recordings (S=9, 0.17-0.30).

Overview of Study Effects (Groups 5 & 7)		
	Researcher Effects	**Recorder Effects**
Group 5 (Whole Task)	n=7, 30s	n=4, 39s
Group 5 (Session 1)	n=5, 25s	n=2, 28s
Group 5 (Session 2)	n=2, 5s	n=2, 11s
Group 7 (Whole Task)	n=7, 46s	n=13, 2m52s
Group 7 (Session 1)	n=5, 36s	n=8, 1m39s
Group 7 (Session 2)	n=2, 10s	n=5, 1m13s

Table 6.22

Secondly, the responses in Table 6.21 coincide with the significant level of recorder-instigated events in the verbal data for Group 7; over three and a half times that observed with Group 5. In addition to who would hear the recordings, these related to either discussion about how it worked (Group 7, S=10, 3.04-3.17), or about what was caught on tape (Group 7, S=14, 1.01-1.45). In the case of Group 5, much of these effects involved speaking directly to the tape recorder. Although the response from Group 5 to Q8 in Questionnaire 2 (Appendix 8) reported them to have talked less, this was not supported by the verbal data or the structured observation.

6.6.4. Summary of Differences in Social & Intrinsic Factors

1. Though lower during the second session, levels of group tension were very high for Group 7, with evidence this was linked to managerial traits.
2. Group 5 were not significantly affected by the competitive dynamic of the task, however, negative effects from this were comparatively high for Group 7.
3. Effects from the researcher were similar in the case of both Group 5 and Group 7, the levels of which were also similar to effects from the recorder for Group 5.
4. Recorder effects for Group 7 were notably higher.

6.6.5. A Framework for Exploring Social & Extrinsic Differences

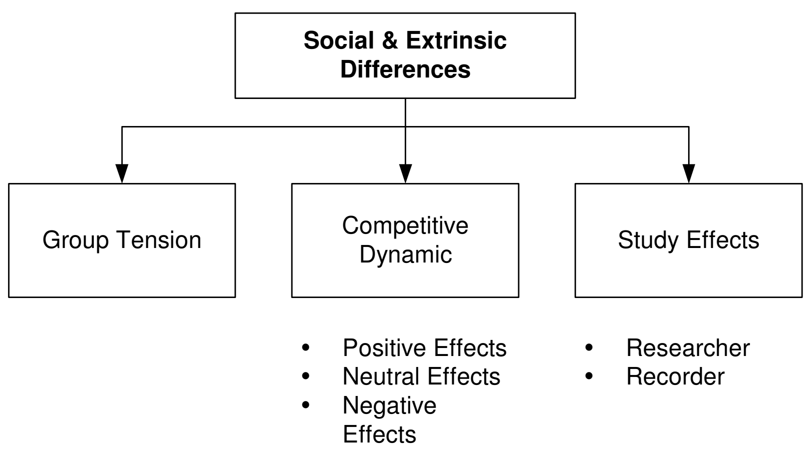


Figure 6.15 – A Framework for Exploring Social & Extrinsic Differences

6.7. Analysis of Remaining Dyads

The following sections discuss the application of the frameworks and definitions established in the previous analytical stage to the data sets of the remaining 3 dyads in the study. As per the analytical structure (Figure 6.2), this was done in decreasing rank order and the results and analysis will be presented in the same order for each. In the interests of focus, the tables presented throughout this section are truncated to show only areas of notable difference.

6.8. Overview of Dyad 2: Groups 6 & 13

Table 6.23 provides an overview of the groups in this dyad, ranked 2nd of four. The academic performance (a.p.) of native schools is based upon the number of pupils gaining 5 or more standard grade qualifications at level 4 or above in 2002.

Overview of Groups in Dyad 2		
	Group 6	**Group 13**
Solution Cohort	**Good**	**Poor**
Native School	2 (a.p. = 88%)	3 (a.p. = 59%)
Deprivation Level	Low	Medium
Gender	Female	Male
Number of Members	4	3*

Table 6.23

Group 13 was significantly affected by fluctuating attrition*. Four pupils were originally allocated but during the first session of the main task, one pupil was absent, whilst during the second session, this pupil returned and a different pupil was absent. This resulted in a maximum of three pupils and a different group composition for each session. The effects of this were considerable and are discussed in the following sections.

Photographs of the group solutions can be found in Appendix 16.

6.8.1. Set 1: Knowledge Differences

This section reports on findings for Dyad 2 from the structures unit, the knowledge explicitly verbalised during the activity, and the solution as a representation of knowledge.

6.8.1.1. Knowledge: Attainment in Structures Unit

The overall performance of each group is given in Table 6.24.

Attainment of Groups 6 & 13 in Core Areas		
	Group 6 Score (s.d.)	**Group 13** Score (s.d.)
Overall Unit (all questions)	77% (3.74)	78% (1.29)
Core Area 1: Tension & Compression	88% (1.26)	93% (0.58)
Core Area 2: Triangulation	67% (0.82)	67% (0.00)
Core Area 3: Turning Moments	58% (1.73)	100% (0.00)
Average of Core Areas	71%	86.7%

Table 6.24

Although the attainment for the overall unit of work is very similar, Group 13 achieved higher overall scores for the three core elements. Of note here is both the lower standard deviation suggesting greater similarity in understanding and that they achieved 100% in the most conceptually demanding area.

6.8.1.2. Knowledge: Verbalised During Activity

As seen with Dyad 1, the overall levels of verbalised knowledge were again low with little difference observed in the use of personal knowledge or task knowledge prior to construction. In the latter case, both groups simply used it as a basis for assessing the legality of proposals made; as seen below for that observed during construction also. The most significant differences, however, were observed in use of task knowledge during construction and in knowledge of the associated concepts and principles. Table 6.25 lists results for these key areas of difference.

As indicated, during construction, Group 6 verbalised more task knowledge that was contextually correct than did Group 13. Most of the instances with group six related to the fact that parts of the bridge were not allowed to be constructed in the water (e.g. Group 6, S=10, 2.45-2.48; S=8, 3.20-3.30). This was true for one of counts in Group 13, and the other pertained to the time allocated (Group 13, S=4, 4.50-4.52). Of equal significance was the fact that Group 6 made virtually no use of explicit knowledge that related to the cantilever system and that of the occasions where Group 13 did, the seven that arose during discussion with the teacher revealed a level of uncertainty as illustrated in Excerpt 33.

Overview of Verbalised Knowledge (Groups 6 & 13)			
	Task Knowledge During Construction (Correct)	**Knowledge of C&P* Assisted (Correct)**	**Knowledge of C&P* Assisted (Incorrect-Unsure)**
1 : Group 6 (All)	n=7, 22s	n=1, 2s	n=0, 0s
2 : Group 6 (Session 1)	n=4, 16s	n=1, 2s	n=0, 0s
3 : Group 6 (Session 2)	n=3, 6s	n=0, 0s	n=0, 0s
4 : Group 13 (All)	n=2, 3s	n=8, 20s	n=7, 9s
5 : Group 13 (Session 1)	n=1, 1s	n=7, 15s	n=7, 9s
6 : Group 13 (Session 2)	n=1, 2s	n=1, 5s	n=0, 0s

Table 6.25

**C&P = Concepts & Principles*

Here the teacher had just asked the pupils what shapes the members of the forth road bridge are as a means to aid them in considering this within their own design.

Excerpt 33

Pupil 1: "Squares.. rectangles…"

Pupil 2: "Diagonal lines… circles…"

Teacher: "What shape are these? That's the Forth Rail Bridge…"

Pupil 1: "Triangles.."

Pupil 2: "Crosses.."

Pupil 1: "so it cr.. its like a box, but only triangles in there….?"

(Group 13, S=2, 3.46-3.59)

Whilst this many seem to be eliciting personal knowledge, the teacher is encouraging pupils to link the rolled paper example during the structures unit with its role inside a structure (*see* Figure 6.1, Page 171). The group's attainment for this section was 93%, and there is a poster in the class to which they are referring. Though the pupils do arrive at the fact they are cylindrical, it is unclear whether difficulty was due to questioning, difficulty in recalling, crossing contexts, or a degree of each.

Idea generation was fairly continuous throughout the activity of Group 6 accounted for by 23.75% of all codes recoded. This was higher than for Group 13 with only 10.5% of codes pertaining to idea generation.

6.8.1.3. Knowledge: The Solution as Manifest Knowledge

The analysis of photographs revealed 8 main developments in each of the group's solutions. These were confirmed by the pupils' post-task questionnaires and are illustrated in Figures 6.16 and 6.17.

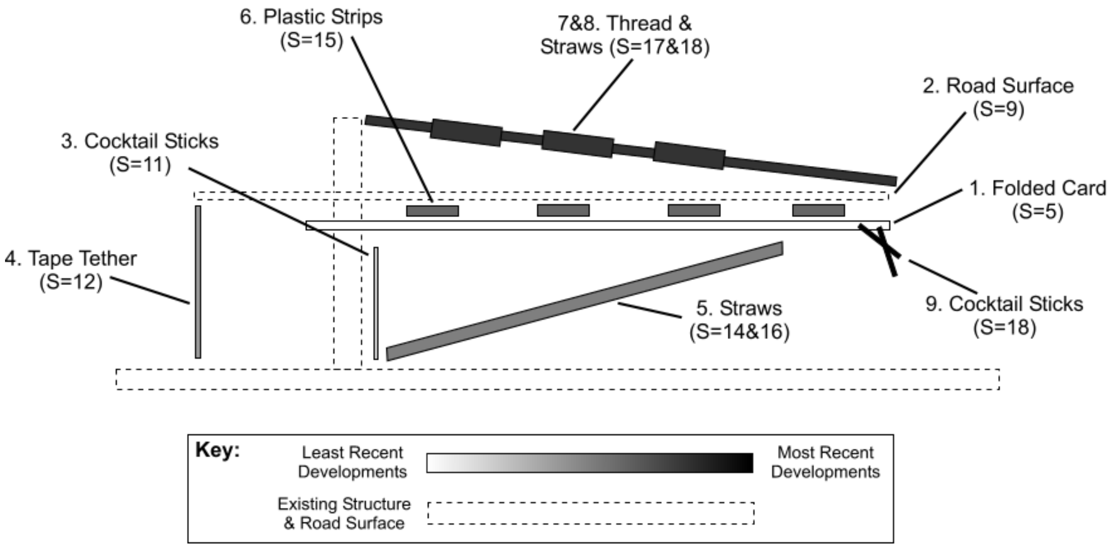


Figure 6.16 – Development of Solution by Group 6

As shown, 3 of the 9 main developments identified (straws on thread, tape tether and cocktail sticks at the front of the road), served no structural purpose within the solution. Aside from this, there was no evidence of misconception in the placement, configuration or choice of materials.

In terms of function, the bridge in Figure 6.17 failed for the same reasons as the solution produced by Group 7: a failure to make the road surface rigid. Conceptually, only the cocktail stick (S=12) served no functional purpose and, in the same manner as observed with Group 7, the practical execution was exceptionally poor which may indicate comparatively lower tacit knowledge than seen with either Group 5 or 6. However, the fact that the thread, functioning as tie, was attached before any attempt was made to strengthen the road, suggests a lack of knowledge about the way in which the structural system functions. Card being added to the road surface following this represents the first in a series of largely reactive developments (3, 4, 6, and 7) instigated to mitigate the effects of the structural requirement overlooked at the start. This was observed despite this group attaining higher scores in the structures unit.

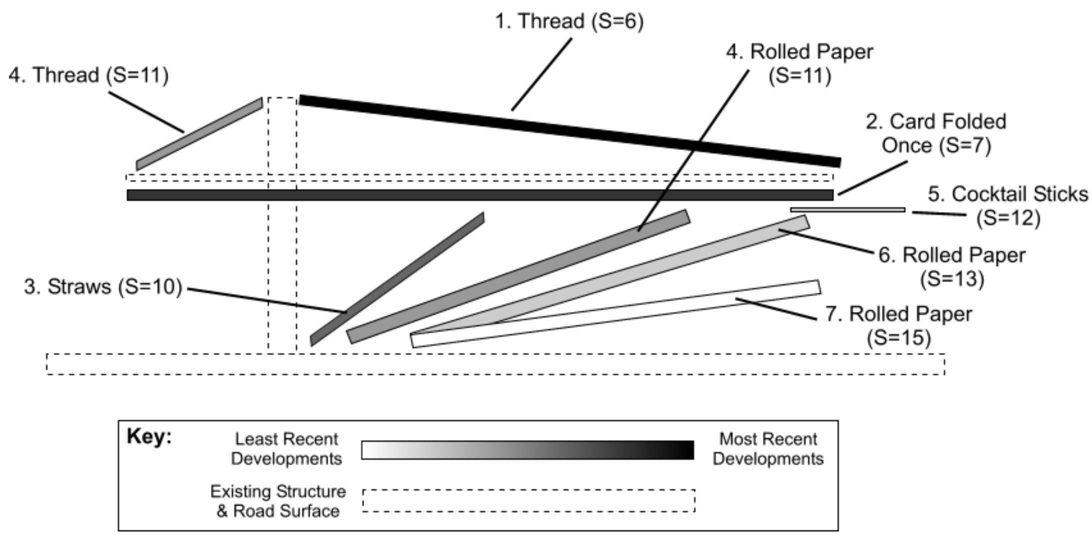


Figure 6.17 – Development of Solution by Group 13

6.8.1.4. Summary of Difference in Knowledge (Dyad 2)

1. Group 13 attained a similar score to Group 6 for the overall unit and in the triangulation section, but achieved higher scores for forces and turning moments.
2. Group 6 verbalised more task knowledge than Group 13.
3. Group 6 made virtually no use of explicitly verbalised knowledge that related to the cantilever system.
4. Photographic evidence of Group 13 highlighted a deficit in knowledge regarding how the developing solution functions as a structural system.

6.8.2. Set 2: Process Differences

This section presents and considers the results for Dyad 2 for the overall problem solving process, and the basic phases of activity the groups engaged with.

6.8.2.1. Global Process: Pattern of Solution Development

The development plots for each solution suggests that Group 6's solution grew more steadily than the solution of Group 13 (Appendix 12). However, closer analysis revealed that, as observed with Group 7 (Dyad 1), Group 6 removed some developments. These took place during both sessions and are signified by the difference bars in Figures 6.18 and 6.19 below.

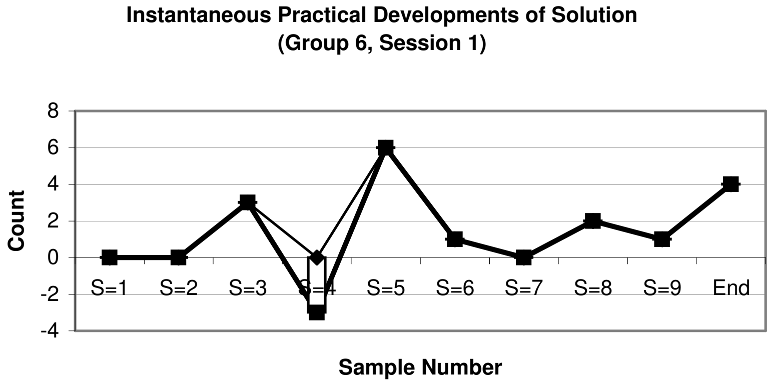


Figure 6.18

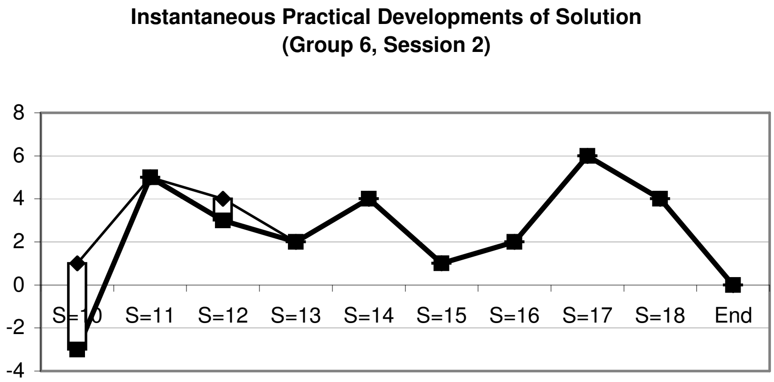


Figure 6.19

The removal of material (illustrated by difference bars) shown at S=4, S=10 and S=12 were all minor changes involving just straws and tape; not of the nature previously seen with Group 7 (Dyad 1). The developments for Group 6 appeared as temporary aids for solution development and the trialling of ideas in view of problems with the placement of straws and cocktail sticks (S=4-5, 3.35-0.30) certainly support this. Group 13 did consider re-starting the solution during the second session, but decided against this (S=10, 1.05-1.15) and there was evidence within the photographs that ideas with cocktail sticks had been tried and abandoned (S=10).

6.8.2.2. Global Process: Phases of Activity

Within this dyad, Group 6 initiated construction 10m05s into the activity, and Group 13 began after 14m10s. The structured observation confirmed no construction activity with Group 6 during S=2. Both groups were able to established a range of suitably considered initial ideas (e.g. Group 13, S=2, 1.25-1.38; Group 6, S=2, 1.40-1.48) and, in contrast to Group 7 (Dyad 1), identified starting points. Group 13, although commencing before sketching was complete, chose to begin with a thread development and continue from there (S=3, 2.58). In contrast to Dyad 1, Group 13 from the poor cohort spent 4m04s longer in the conceptual phase than Group 6 from the good cohort.

Both groups also engaged in a period of sketching (Group 6, S=2, 0.08; Group 13, S=2, 0.32). This was confirmed during the structured observation for Group 6 (S=2: 36% of recorded codes were for sketching). As found with Dyad 1, this promoted new ideas and refinements.

6.8.2.3. Summary of Differences in the Global Process (Dyad 2)

1. The development of Group 6's solution appeared steadier over time than Group 13's and although there was evidence that Group 6 removed developments, these were temporary and of little significance.
2. In contrast to Dyad 1, Group 13 from the Poor Cohort spent longer in the conceptual phase than Group 6, and both groups engaged in sketching initial design ideas.
3. Both groups established sufficiently considered initial ideas prior to starting construction.

6.8.3. Management

This section reports on the differences between Group 6 and 13 with respect to the three management dimensions: Group Involvement, Efficiency and Planning.

6.8.3.1. Management: Group Involvement

Table 6.26 illustrates the results for instances of 'Poor Group Involvement' and for 'Role/Task Allocation/Adoption'. No difference between groups was observed with respect to 'Fragmented Vision', the third dimension of 'Group Involvement'.

Table 6.26 indicates a strong similarity to the findings of Group 5 in Dyad 1 with no instances of poor group involvement and an even distribution of role and task allocation between both the first and second sessions. Although the first session of activity for Group 13 shares similar characteristics, the nature of Group Involvement during the second session is seen to change dramatically in respect of both measures. This is recognised as one of a range effects arising from the previously described change in group membership between the first and second sessions[3].

Overview of Group Involvement (Groups 6 & 13)		
	Group Involvement (Poor)	**Group Involvement (Tasks & Roles)**
1 : Group 6 (All)	n=0, 0s	n=30, 1m10s
2 : Group 6 (Session 1)	n=0, 0s	n=14, 34s
3 : Group 6 (Session 2)	n=0, 0s	n=16, 37s
4 : Group 13 (All)	n=14, 59s	n=24, 52s
5 : Group 13 (Session 1)	n=0, 0s	n=16, 35s
6 : Group 13 (Session 2)	n=14, 59s	n=8, 17s

Table 6.26

Those instances of poor group involvement during the second session were extreme to the point that one pupil (Pupil 2), who contributed well during the first session, was purposely disenfranchised from the activity. Excerpt 34 illustrates the group's revised dynamic which was observed throughout Session 2.

Excerpt 34

Pupil 1: "Andrew, right, me an' Alan sussed it-oot, so you canny dae nu-hun.."

Pupil 2: "Well you can tell me.."

Pupil 1: "Me and And… me and Alans-in charge.."

Pupil 2: "No you're no, am back in your group.."

Pupil 3: "Tough."

(Group 13, S=11, 4.30-4.42)

The accompanying drop in role and task allocation was partly due to the fact that only two of the three pupils were permitted to do anything. It is also noteworthy that, in considering the problem solving task, the teacher for Group 13 reported better pupil involvement than normal in terms of the class as whole (Appendix 6).

[3] In addition to the aforementioned group changes, one pupil temporarily left for an appointment during the second session in error and returned to the group shortly afterwards.

6.8.3.2. Management: Increasing Efficiency

Groups in this Dyad made relatively few attempts to increase efficiency. Whilst durations were identical (11s), Group 13 made twice as many as Group 6. All attempts were in relation to speeding up the process other than one attempt by Group 6 to initiate tasks in parallel (Group 6, S=12, 1.39-1.41).

6.8.3.3. Management: Planning

The use of planning by both groups in this dyad was remarkably similar. Whilst instances of poor planning were few, more were observed with Group 6 who also engaged in slightly more prior planning and sequencing. Table 6.27 shows the breakdown of these factors for each group.

Occurrences of poor planning in Group 6 involved such things as pupils accidentally cutting parts error (e.g. S=15, 2.44-2.47), constructing developments that were not required (e.g. S=6, 2.11-2.16) and integrating the wrong parts (e.g. S=7, 1.10-1.13). However, as seen with group involvement, the starkest contrast is again between the first and second sessions of Group 13's activity.

Overview of Planning (Groups 6 & 13)		
	Results of Poor Planning	**Planning, Sequencing or Stating Requirements**
1 : Group 6 (All)	n=6, 17s	n=48, 3m53s
2 : Group 6 (Session 1)	n=5, 14s	n=25, 2m15s
3 : Group 6 (Session 2)	n=1, 3s	n=23, 1m38s
4 : Group 13 (All)	n=2, 14s	n=35, 3m15s
5 : Group 13 (Session 1)	n=1, 12s	n=28, 2m54s
6 : Group 13 (Session 2)	n=1, 2s	n=7, 21s

Table 6.27

Analysis of planning distribution for Group 13 showed that instances were regular over the 26 minute period between the 13th and 39th minute of the first session; this accounted for 89% of the total time spent planning. The second session was characterised by less overall task discussion accompanying a greater level of construction activity. This was reflected by the structured observation during S=11 and S=13 where construction activity alone accounted for an average of 63% of all codes recorded (Appendix 11). Of the planning that did occur within this, most cited the global requirements for the solution (e.g. S=12, 2.53-2.56) and one instance had an element of sequence (S=12, 1.22-1.34).

6.8.3.4. Summary of Differences in Management

1. Only Group 13 exhibited poor instances of group involvement which occurred entirely during the second session after a change in group composition.
2. Similar levels of group involvement were observed for both groups, however, it was more prevalent for Group 13 during the first session. Distribution was even for Group 6.
3. Groups made similar use of attempts to increase efficiency.
4. Group 6 was affected by more counts of poor planning and, whilst slightly more planning was seen with Group 6, 89% of that observed for Group 13 was during the first session.

Table 6.28 below shows the combined positive and negative features of planning for each group in terms of count and duration.

Overview of Positive & Negative Management Traits (Groups 6 & 13)		
	Management (Negative)	**Management (Positive)**
1 : Group 6 (All)	n=8, 29s	n=78, 5m04s
2 : Group 6 (Session 1)	n=7, 26s	n=38, 2m48s
3 : Group 6 (Session 2)	n=1, 3s	n=40, 2m16s
4 : Group 13 (All)	n=17, 1m19s	n=61, 4m12s
5 : Group 13 (Session 1)	n=2, 18s	n=45, 3m32s
6 : Group 13 (Session 2)	n=15, 1m01s	n=16, 40s

Table 6.28

6.8.4. Process Engagement

This section describes the nature of the reflective processes that each group initiated, prior to and during construction.

6.8.4.1. Process Engagement: Reflection During the Conceptual Phase

This section reports on the breakdown of reflection for each group during the conceptual phase of problem solving. For Group 6, this lasted 10m05s and for Group 13, this lasted 14m10s. Of the three categories of reflection (Task, Analytical and Declarative), little difference between groups was observed with the former two. Group 13 engaged in task reflection five times whilst three were coded for Group 6. As with Dyad 1, these pertained to what was legal within the problem solving task.

Though both Group 6 and 13 engaged in a similar level of analytical reflection (n=14, 48s and n=12, 32s, respectively), this was notably higher than that observed for Group 5 (n=8, 26s). For Group 6, most of these were seen in an extended discussion about whether a suggested idea would work or not (S=2, 0.45-1.32). These revealed predictive statements as well as knowledge of functional relationships between parts of the structure. For Group 13, occurrences were more discrete, but still tied closely to suggestions and performance. One such reflection predicted that a given proposal would cause the structure to fail (S=2, 2.54-2.56).

The most significant difference between the groups during this phase, however, was the considerably greater use of declarative reflection by Group 13. There were 46 counts totalling 1m22s in duration compared to just 17 by Group 6 lasting 29s. In both groups, these largely involved the positive or negative appraisal of ideas, but were responsible for Group 13 exhibiting twice the overall reflection of Group 6 at this stage (Group 13, n=60, 2m02s; Group 6, n=31, 1m21s).

6.8.4.2. Process Engagement: Reflection During Construction

The greater overall use of reflection prior to construction did not hold true during construction with Group 6 engaging in reflection for 4m18s more than Group 13. The total durations (Group 6: 7m08s’ Group 13: 2m50s) were comparatively lower than both respective groups in Dyad 1. Task reflection did not occur with Group 13 during this phase and was minimal with Group 6. As such, Table 6.29 below illustrates the differences with the remaining two forms of reflection.

As shown in Table 6.29, there is a stark difference in the use of both forms of reflection with almost no use of analytical reflection by Group 13 during the second session. Despite variation in counts, reflection was quite evenly distributed between sessions in almost all cases.

Overview of Reflection (Groups 6 & 13)			
	Reflective (Analytical)	**Reflective (Declarative)**	**Reflection During Construction (Total)**
1 : Group 6 (All)	n=55, 2m39s	n=151, 4m16s	n=206, 6m55s
2 : Group 6 (Session 1)	n=30,1m29s	n=72, 1m55s	n=102, 3m24s
3 : Group 6 (Session 2)	n=25, 1m10s	n=79, 2m21s	n=104, 3m31s
4 : Group 13 (All)	n=13, 34s	n=72, 2m15s	n=85, 2m49s
5 : Group 13 (Session 1)	n=9, 21s	n=37, 1m10s	n=46, 1m31s
6 : Group 13 (Session 2)	n=4, 13s	n=35, 1m05s	n=39, 1m18s

Table 6.29

Despite there being a notable effect in Management Processes from the altered composition of Group 13 half way through, the effect did not appear to extend to reflective processes which were comparatively similar for both sessions.

6.8.4.3. Process Engagement: Reflection During Construction

1. Overall, Group 6 engaged in significantly more reflective processes than Group 13
2. Prior to construction, the use of analytical reflection by groups was similar, but Group 13 utilised significantly more declarative reflection.
3. During construction, Group 13 used very little analytical reflection compared with Group 6 and around half the amount of declarative reflection.
4. For both groups, reflection during the construction phase was fairly evenly distributed between the first and second session.
5. Reflective process did not appear to be adversely affected by the change of composition in Group 13.
6. The fact the group from the good cohort engaged in more overall and analytical reflection is consistent with findings from the first dyad.

6.8.5. Set 3: Social & Extrinsic Factors

The following section presents and analyses the presence of group tension, as well as the effects of the competitive dynamic and study design on Group 6 and 13.

6.8.5.1. Social & Extrinsic Factors: Group Tension

There were no instances of group tension noted with Group 6. By contrast, a total of twenty counts of tension were recorded with Group 13, all during the second session. Excerpts 35 and 36 show typical examples of this tension which were broadly due to the shift in group composition and the resultant disenfranchisement of one pupil.

Excerpt 35

(Pupil 2 returns after short absence from class)

Pupil 1: "That's a load-e gid, we hoped you were gone!"

Pupil 2: "Aye… so did a, but…."

(Group 13, S=11, 2.45-2.51)

Excerpt 36

Pupil 2: "Sir, they're not gonna let me do anythin', they say that am not a part of it.."

Pupil 1: "We never said nu'in', we.. we.. no….."

Pupil 2: (Shouting) "Yeh you did! You said am not part of it 'cause a was away…"

(Group 13, S=13, 0.01-0.08)

6.8.5.2. Social & Extrinsic Factors: Competitive Dynamic

The overall effects of the competitive dynamic were seen to affect both groups, though far more significantly in the case of Group 6. In total, 37 counts were coded equal to a duration of 3m59s which was 62% longer than the 12 counts observed for Group 13 (Duration=1m30s). As shown in Table 6.30, the greatest differences were seen in terms of negative and neutral effects.

Group discourse revealed that of the negative effects coded for Group 6, seventeen counts related to espionage (e.g. Group 6, S=10, 2.30-2.43) and interference between groups (e.g. Group 6, S=13, 1.54-2.14). The remaining two involved pupils negatively comparing their own solution to that of other groups (Group 6, S=End (Session 2), 0.15-0.19). Exactly the same breakdown was observed with Group 13, albeit to a lesser extent. The neutral events throughout the activity of Group 6 involved passing compliments between groups and commenting on the progress of other groups.

Effects of Competitive Dynamic (Groups 6 & 13)			
	Negative	**Positive**	**Neutral**
1 : Group 6 (All)	n=19, 2m06s	n=4, 14s	n=14, 1m39s
2 : Group 6 (Session 1)	n=6, 1m06s	n=0, 0s	n=5, 50s
3 : Group 6 (Session 2)	n=13, 1m	n=4, 14s	n=9, 49s
4 : Group 13 (All)	n=10, 1m14s	n=0, 0s	n=2, 16s
5 : Group 13 (Session 1)	n=5, 34s	n=0, 0s	n=1, 6s
6 : Group 13 (Session 2)	n=5, 40s	n=0, 0s	n=1, 10s

Table 6.30

Group 6 was, by comparison, far more concerned by the activity of other groups and, as was noted with reflective processes, the change in group membership did not appear to alter Group 13's response to the competitive dynamic.

6.8.5.3. Social & Extrinsic Factors: Study Effects

Despite Group 6 exhibiting a more significant response to the competitive dynamic than Group 13, the opposite effect was observed in relation to the presence of the researcher and audio recorder. Table 6.31 shows the counts and durations for each group.

Overview of Study Effects (Groups 6 & 13)		
	Study Effects (Researcher)	**Study Effect (Recorder)**
1 : Group 6 (All)	n=2, 4s	n=10, 35s
2 : Group 6 (Session 1)	n=2, 4s	n=5, 15s
3 : Group 6 (Session 2)	n=0, 0s	n=5, 20s
4 : Group 13 (All)	n=6, 25s	n=17, 2m05s
5 : Group 13 (Session 1)	n=3, 17s	n=5, 56s
6 : Group 13 (Session 2)	n=3, 8s	n=12, 1m09s

Table 6.31

Both counts for study effects with Group 6 stemmed from photographs being taken. Though this was also present with Group 13 (Group 13, S=2, 0.14-0.23), two counts were instigated by the observational role of the researcher and the fact the pupils were supposed to address the teacher instead (e.g. Group 13, S=End $_{\text{Session 2}}$, 0.45-0.50). In addition to the minimal concerns voiced by Group 6 over what was recorded, most of the recorder effects in Group 13 involved physically moving the recorder (Group 13, S=9, 0.59-1.02) and attempting to cover the microphone (Group 13, S=3, 2.26-2.52). These had a negligible effect on what was recorded.

6.8.5.4. Summary of Differences for Social & Extrinsic Factors (Dyad 2)

1. Group 13 suffered from significant level of group tension whilst none was observed with Group 6.
2. Virtually all instances of tension occurred during the second session of problem solving activity after a change in group composition; tension centered on poor group involvement.
3. Despite the competitive dynamic affecting both groups to some degree, significantly more neutral effects and around twice as many negative effects were observed with Group 6.
4. The most significant difference in study effects was the comparatively high level of instances arising from the presence of the recorder with Group 13.

6.9. Overview of Dyad 3

Table 6.32 provides an overview of the groups in this dyad, ranked 3rd of four.

Overview of Dyad 3		
	Group 12	**Group 4**
Solution Cohort	**Good**	**Poor**
Native School	3 (a.p. = 59%)	1 (a.p. = 61%)
Deprivation Level	Medium	High
Gender	Female	Male
Number of Members	4	5

Table 6.32

6.9.1. Set 1: Knowledge Differences

This initial section reviews findings from the structures unit, the verbalisation of knowledge during problem solving and the knowledge implicit within the final solutions.

6.9.1.1. Knowledge Differences: Attainment in Structures Unit

The overall performance of each group is given in Table 6.33.

Attainment of Groups 12 & 4 in Core Areas		
	Group 12 Score (s.d.)	**Group 4** Score (s.d.)
Overall Unit (all questions)	85% (0.71)	65% (2.65)
Core Area 1: Tension & Compression	90% (0.82)	83% (1.15)
Core Area 2: Triangulation	100% (0.0)	80% (1.34)
Core Area 3: Turning Moments	83% (0.82)	70% (1.52)
Average of Core Areas	91%	77.7%

Table 6.33

Although the overall difference in attainment between Group 12 and 4 was the biggest for the Dyads examined thus far, in general terms, it was still high. Group 12 exhibited a lower standard deviation on all counts suggesting a greater level of similarity in answers and achieved 100% in the section exploring triangulation. The average attainment of Group 12 for the three core areas was 14% higher than that of Group 4.

6.9.1.2. Knowledge Differences: Verbalisation During Activity

The level of verbalised knowledge in both groups was again very low. Though levels of personal knowledge were low, Group 4 engaged with this for twice the duration Group 12 did (20s and 11s) and both made comparisons to existing bridges. No appreciable difference was seen in use of Task Knowledge; however Group 4 failed to draw on it at all prior to starting the practical phase. Though minimal, the most noted differences lay with the use of concepts and principles, the results from which are shown in Table 6.34.

Overview of Verbalised Knowledge (Groups 12 & 4)			
	Knowledge of C&P Assisted (Correct)	**Knowledge of C&P Assisted (Incorrect-Unsure)**	**Knowledge of C&P Independent (Correct)**
1 : Group 12 (All)	n=8, 13s	n=3, 10s	n=8, 18s
2 : Group 12 (Session 1)	n=6, 10s	n=2, 7s	n=7, 16s
3 : Group 12 (Session 2)	n=2, 3s	n=1, 3s	n=1, 2s
4 : Group 4 (All)	n=0, 0s	n=0, 0s	n=1, 5s
5 : Group 4 (Session 1)	n=0, 0s	n=0, 0s	n=0, 0s
6 : Group 4 (Session 2)	n=0, 0s	n=0, 0s	n=1, 5s

Table 6.34

As illustrated, in contrast to those counts coded for Group 12, Group 4 did not engage in discussion drawing upon knowledge of the underlying concepts with the class teacher. Where this did happen with Group 12, both certainty and uncertainty were uncovered. All instances in which there was uncertainty related to the strongest shapes for given materials (e.g. Group 12, S=6, 0.34-0.42; S=9, 2.06-2.10) although those instances where the group was correct, related to the same thing. The uncertainty may be due to difficulties with the contexts in which knowledge recall was elicited. All of the counts for the correct use of such knowledge by Group 12 (out with teacher discussion) related to triangulation (e.g. Group 12, S=7, 0.12-0.14) with the exception of one where a pupil drew on knowledge of material strength when reflecting upon material choice (Group 12, S=9, 3.22-3.24).

6.9.1.3. Knowledge: The Solution as Manifest Knowledge

The main developments identified in the groups' solutions are shown in Figures 6.20 and 6.21. The photographic analysis demonstrated salient differences in groups' knowledge of how the bridge functions as a structural system, and the interrelationship between component parts.

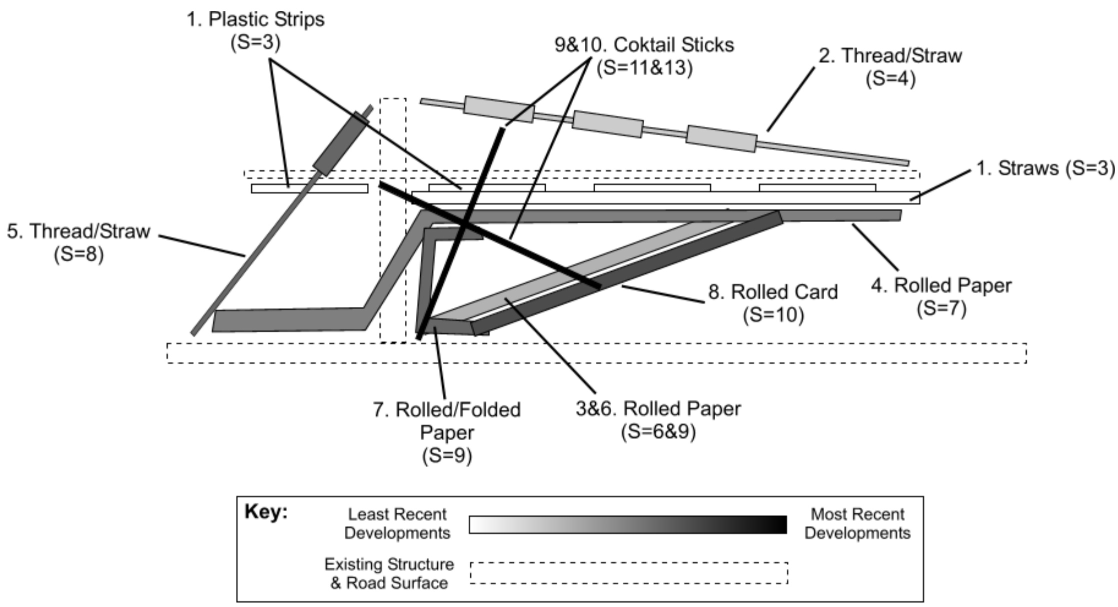


Figure 6.20 – Development of Solution by Group 12

Notwithstanding the addition of the straws along the lengths of thread, three of the ten developments identified (Thread/Straw S=8, Rolled/Folded Paper S=9, and Plastic Strips S=3) made little to functional contribution to the structure. In the first instances, the thread was not attached to the road surface; the effect of the latter two was diminished by folding and placement/orientation. The configuration, placement and material choice for the remaining seven developments was good evidencing knowledge of triangulation and material properties. It was also noted that the thread and main bracing under the road featured in the design drawings prior to construction.

The solution by Group 4 (Figure 6.21) is more conceptually erratic by comparison. It did exhibit both strengthening of the road surface (S=2) and partial measures to mitigate deflection (S=9) and hence was not subject to failure in the manner as the poorer groups in the previous dyads. What was distinct about this solution; however, was that these were the only developments from the nine identified that functioned correctly within the structural system. Though the group demonstrated awareness that triangulation was important, the folded straw triangle was not connected to anything on the bridge.

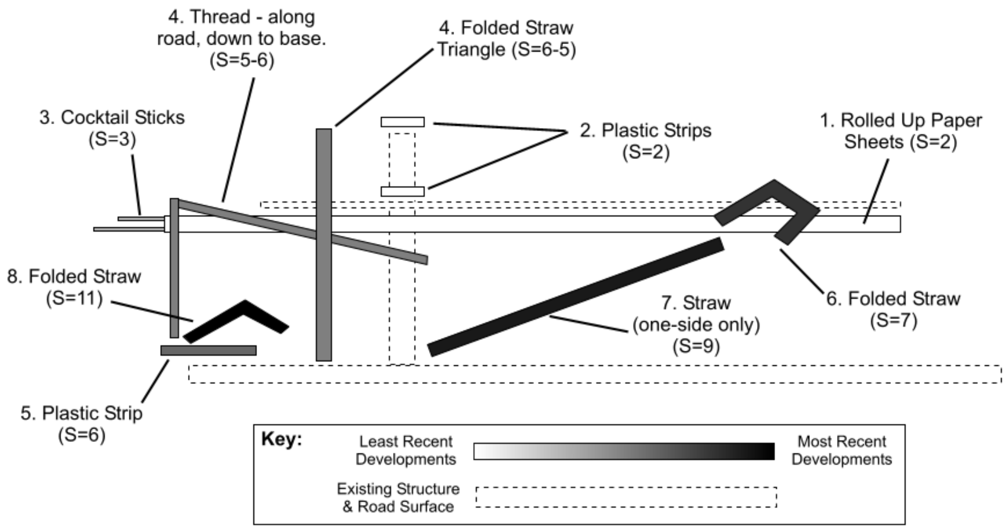


Figure 6.21 – Development of Solution by Group 4

The use of thread in tension served only to add unwanted camber to the rear of the road surface. Given that all but two developments fail to integrate with the structure suggests a lack of more qualitative knowledge about how the solution functions as a structural system and the interaction of components to enhance performance. Comments from the Delphi experts highlighted the error with triangulation and poor quality of execution.

6.9.1.4. Summary of Differences in Knowledge (Dyad 3)

1. Group 12 performed to a higher level than Group 4 during the structures unit.
2. Verbalised knowledge by both groups was minimal, although notably less for Group 4 with regard to underlying concepts and principles.
3. 70% of the key developments within Group 12's solution related directly to structural concepts and demonstrated a good knowledge of material properties, concepts and principles.
4. In the solution by Group 4, only 22% of the key developments functioned within the structural system suggesting a lack of understanding and qualitative knowledge associated with the system a whole.

6.9.2. Set 2: Process Difference

This section reports on differences found in the overall development of the solution, the management of the problem solving process and the nature of the reflective processes the groups engaged with.

6.9.2.1. Global Process: Pattern of Solution Development

The solution development plots (Appendix 13) indicate that, although the level of development in Group 12's solution exceeds that of Group 4, both groups began constructing relatively early. The biggest difference was in the rate of construction with Group 4 achieving 80% of the total development level by the end of the first session compared with only 40% at the same stage by Group 12.

6.9.2.2. Global Process: Phases of Activity

The verbal data demonstrated that Group 12 spent 5m18s longer in the conceptual phase than Group 4. Group 4 began construction after 4m27s, effectively the same time seen with Group 7, however Group 12 began after 9m45s. As in previous cases, this comparative drop in time will have an effect on those measures that consider occurrences before and after construction has begun. The structured observation for S=3 revealed that although construction began with Group 12, sketching of ideas continued in parallel for another 2 minutes.

Of particular significance during this phase is the fact that Group 4 began construction having made almost no suggestions for how to begin and without establishing any form of idea. The teacher makes various suggestions to the group to try and stimulate thinking (e.g. S=1, 2.35-2.45), though these are explicitly dismissed by the pupils. As will be later discussed, this group are very suspicious of, and heavily affected by, the fact they are part of a study.

6.9.2.3. Summary of Differences in the Global Process (Dyad 3)

1. Both groups began construction quite early but Group 4 developed their solution far more rapidly than Group 12.
2. Group 12 spent significantly longer in the conceptual phase of problem solving and achieved some starting ideas.
3. Group 4 began construction after just 4m27s without having established any ideas.

6.9.3. Management

This section explores those differences evident with respect to group involvement, attempts to increase efficiency, and aspects of planning between Groups 12 and 4.

6.9.3.1. Management: Group Involvement

Instances in which group members had different notions about what the group should do were both infrequent and minor. A total of 15s and 6s were coded for Group 12 and 4 respectively. The starkest differences arose with regard to traits of poor group involvement and in the utilisation of tasks and role. These differences are listed in Table 6.35.

Overview of Group Involvement (Groups 12 & 4)		
	Group Involvement (Poor)	**Group Involvement (Tasks & Roles)**
1 : Group 12 (All)	n=0, 0s	n=20, 49s
2 : Group 12 (Session 1)	n=0, 0s	n=14, 36s
3 : Group 12 (Session 2)	n=0, 0s	n=6, 13s
4 : Group 4 (All)	n=13, 51s	n=9, 21s
5 : Group 4 (Session 1)	n=6, 16s	n=2, 3s
6 : Group 4 (Session 2)	n=7, 35s	n=7, 18s

Table 6.35

Previously, in Dyads 1 and 2, much of the poor group involvement related to either monopolisation or disenfranchisement, and this is also reflected in Group 4. For example, one pupil complains to the teacher that two other group members are not doing enough (S=13, 1.28-1.43); a suggestion is also made that the solution was alright until another pupil became involved (S=15, 0.10-0.23). However, some of the earlier instances coded near the beginning of the first session relate to a lack of engagement in the task by the group as a whole (S=1, 2.42-2.44). This is largely symptomatic of the pupils' negative perception of the study.

The use of role and task allocation and adoption featured more strongly with Group 12. Instances observed involved eliciting pupils in assisting with construction (S=4, 5.04-5.07), and overtly allocating tasks (S=13, 2.26-2.29). In Group 4, tasks were mostly allocated (S=12, 1.17-1.20), with a few being taken on by pupils (S=2, 1.27-1.29).

6.9.3.2. Management: Increasing Efficiency

As with Dyad 2, little difference was observed with regard to efficiency measures, although it was slightly more prevalent with Group 12 (Durations: Group 12=14s, Group 4=9s). All instances were time related.

6.9.3.3. Management: Planning

Evidence of the results of poor planning was limited in this Dyad, though slightly greater with Group 4. The most significant of these was a pupil applying a development to the wrong side of the bridge (S=14, 3.25-3.32). This is likely to have stemmed from the nature of communication between group members, recognised to be significantly poorer than observed with Group 12.

Instances of planning had yet greater similarity. Counts and durations for Groups 12 and 4 were (n=19, 1m08s) and (n=15, 53s), respectively. Occurrences across both groups included identifying requirements (Group 12, S=7, 0.49-0.54), sequencing activity (Group 4, S=9, 2.34-2.37; Group 12, S=4, 2.09-2.16), and counting materials in preparation for a given development (Group 4, S=3, 1.42-1.48).

6.9.3.4. Summary of Differences in Management

1. Both groups made use of role/task adoption and allocation, though around twice as many instances were seen with Group 12.
2. Group 4 engaged in a significant level of poor group involvement (51s) with no instances coded for Group 12.
3. Group 12 made more attempts than Group 4 to increase the speed of problem solving.
4. Neither group incurred significant results from poor planning and little difference was noted in the planning that did take place.

The overall counts and durations for the positive and negative management features of each group are given in Table 6.36.

Overview of Positive & Negative Management Traits (Groups 12 & 4)		
	Management (Negative)	**Management (Positive)**
1 : Group 12 (All)	n=1, 3s	n=19, 1m09s
2 : Group 12 (Session 1)	n=0, 0s	n=10, 43s
3 : Group 12 (Session 2)	n=1, 3s	n=9, 26s
4 : Group 4 (All)	n=3, 19s	n=15, 53s
5 : Group 4 (Session 1)	n=1, 5s	n=7, 21s
6 : Group 4 (Session 2)	n=2, 14s	n=8, 32s

Table 6.36

6.9.4. Process Engagement

This section will report on the differences between groups in terms of task, declarative and analytical reflection.

6.9.4.1. Process Engagement: Reflection During the Conceptual Phase

In comparing the phase with previous cohort groups, Group 12 engaged in a similar level of analytical reflection (n=7, 26s) to Group 6, and a greater level than Group 5 (Dyad 1). In stark contrast, Group 4 did not engage in *any* form of reflective process at all prior to commencing with construction. This is concurrent with the fact they undertook no real idea generation during this phase either. Key analytical reflection by Group 12 identified weaknesses (Excerpt 37) and material configurations (Excerpt 38) in proposed solutions.

Excerpt 37

"Let's use a good shape because that bends… its better to use a triangle."

(Group 12, S=2, 0.59-1.01)

Excerpt 38

"…so you would have the plastic, like.. goin' along there, 'cause that would keep it steady, 'cause…"

(Group 12, S=2, 2.38-2.45)

This afforded a level of refinement of ideas not undertaken by Group 4. As seen with the other dyads, the three counts of task reflection (7s) that were coded for Group 12 were in relation to legality of proposals.

6.9.4.2. Process Engagement: Reflection During Construction

Both groups were seen to engage in analytical and declarative reflection after construction had begun but no difference was noted in this dyads negligible use of task reflection. The total count for reflective processes engaged with by Group 4 was 72% of the total coded for Group 12. The overall counts and durations were: Group 4 (n=121, 4m36s) and, Group 12 (n=167, 6m27s). Group 12 undertook reflection for an additional 1m51s and far more reflection occurred with Group 4 in the second session. Although declarative reflection appeared largely similar for both groups, Table 6.37 lists these results alongside those for analytical reflection, in which a bigger difference was observed.

Most of the analytical reflection by Group 12 occurred during the first problem solving session. This may be due to a 61% drop in the estimated number of ideas and the fact that the second session was dominated by large practical developments reliant more upon declarative reflection to control the construction process (*see* Figure 6.20, Page 238).

Overview of Reflection (Groups 12 & 4)		
	Reflective (Analytical)	**Reflective (Declarative)**
1 : Group 12 (All)	n=50, 2m35s	n=123, 3m50s
2 : Group 12 (Session 1)	n=35, 1m49s	n=69, 2m07s
3 : Group 12 (Session 2)	n=15, 46s	n=54, 1m43s
4 : Group 4 (All)	n=26, 1m23s	n=98, 3m09s
5 : Group 4 (Session 1)	n=7, 18s	n=36, 1m16s
6 : Group 4 (Session 2)	n=19, 1m05s	n=62, 1m53s

Table 6.37

The opposite distribution of analytical reflection was observed with Group 4. Excerpt 39 is a typical example of analytical reflection throughout most of this session. This instance arose when diagnosing specific problems in what the pupils had constructed.

Excerpt 40 also provides evidence towards the end of more global reflections on the solution. Irrespective of these differences, all occurrences were tied closely to the physical solution.

Excerpt 39

Pupil 1: "You'll no need that much tape"

Pupil 2: "But see, its just gonni move…"

Pupil 3: "Ah, but its stoppin' it a wee bit.."

(Group 4, S=10, 0.58-1.03)

Excerpt 40

"If that wis a real bridge, the'd be so much weight on it, that bit collapses…"

(Group 4, S=End (Session 2), 4.34-4.38)

6.9.4.3. Summary of Differences in Process Engagement

1. Group 4 did not engage with any form of reflection prior to construction whilst Group 12 drew on analytical, declarative and task; though the latter was negligible.
2. During construction, both groups engaged in declarative reflection quite consistently across both sessions, although it was more frequent with Group 12.
3. Analytical reflection during construction was more evident during the first session for Group 12 and during the second session for Group 4. This was likely symptomatic of differing overall approaches to the problem.
4. Overall, Group 12 reflected for 27% longer than Group 4.

6.9.5. Set 3: Social & Extrinsic Factors

This section will report on difference between groups with respect to group tension and the effects of the task dynamic and study.

6.9.5.1. Social & Extrinsic Factors: Group Tension

Findings for instances of group tension constituted one the most notable differences in this Dyad. Whilst this was negligible in the case of Group 12, with two counts coded for a total duration of 10s, 29 occurrences were evenly distributed between both sessions for Group 4, totalling 4m03s in duration.

Most of the tension within Group 4 was due to the abrupt and sometimes aggressive way in which pupils communicated throughout the process. Examples of this ranged from comparatively mild in which blame was apportioned for sub-standard construction (S=10, 2.28-2.38) through to name calling (S=12, 0.20-0.22), arguing (S=6, 1.46-2.10) and threats of physical violence (S=11, 3.25-3.29). Though activity progressed regardless, the evidence here, and that in relation to managerial traits, show that the group did not work well as a collaborative unit. This is likely to be one of the factors responsible for the shortfalls in the final solution.

6.9.5.2. Social & Extrinsic Factors: Competitive Dynamic

The overall effects of the competitive task dynamic for this dyad lasted for 3m39s which was somewhat lower than the average of 5m12s seen with Dyads 1 and 2. Significantly more overall effects were coded for Group 12. The positive and neutral effects were seen to be both minimal and similar in that both groups stated they were going to win (Group 12, S=7, 2.43-2.47) and passed comment on other solutions (Group 4, S=13, 3.24-3.32). The greatest dissimilarity lay, as seen with previous dyads, in the negative effects. Here, 14 counts (1m47s) were coded for Group 12 in comparison to 5 counts (20s) for Group 4. Virtually all instances coded for Group 12 involved suspicion of copying between groups.

6.9.5.3. Social & Extrinsic Factors: Study Effects

Differences were observed between both groups in terms of recorder and researcher effects. These are shown in Table 6.38.

Overview of Study Effects (Groups 12 & 4)		
	Study Effects (Researcher)	**Study Effect (Recorder)**
1 : Group 12 (All)	n=4, 28s	n=6, 43s
2 : Group 12 (Session 1)	n=4, 28s	n=5, 40s
3 : Group 12 (Session 2)	n=0, 0s	n=1, 3s
4 : Group 4 (All)	n=2, 7s	n=10, 1m31s
5 : Group 4 (Session 1)	n=2, 7s	n=6, 1m03s
6 : Group 4 (Session 2)	n=0, 0s	n=4, 28s

Table 6.38

Table 6.38 shows that researcher initiated effects were notably lower than recorder effects for both groups but that all coded instances lessened during the second session. This was strongly reflected in the responses to the post-task questionnaires: Group 4 said there were no significant negative effects with the researcher, but that the negative effects of the recorder dropped over time. Group 12 said they felt negative effects with both the researcher and recorder, but that both reduced over time.

Though researcher effects were greater for Group 12; almost all counts for both groups were as a result of taking photographs (Group 12, S=4, 0.00-0.16; Group 4, S=4, 2.33-2.35). Moreover, recorder effects for Group 12 largely involved speaking to the tape recorder (e.g. Group 12, S=1, 0.20-0.36). This was not so for Group 4. In the early stages of the activity, some pupils in the group were very suspicious and hostile towards the idea they were being recorded. In view of this, one pupil stated he did not want to do the activity (S=1, 0.12-0.14) and later made the statement: "..am no talkin' while that's there.." (S=1, 3.35-3.37). This did have an effect which lessened with time, however, they were the only group in the sample to exhibit this response.

6.9.5.4. Summary of Difference in Social & Extrinsic Factors

1. Group 4 displayed very high levels of tension between group members whilst virtually none was observed with Group 12. This tension was endemic throughout the group's activity.
2. As seen with the previous dyad, the group from the good cohort (Group 12) was more significantly affected by the competitive dynamic than Group 4 was; most of this effect was negative.
3. Group 12 was more affected by the researcher's presence whilst Group 4 was significantly affected by the tape recorder. The response to this by some pupils was very negative although all recorded study effects for this dyad lessened over time.

6.10. Overview of Dyad 4: Groups 8 & 2

Table 6.39 provides an overview of the groups in this dyad, ranked 4th of four.

Overview of Dyad 4		
	Group 8	**Group 2**
Solution Cohort	**Good**	**Poor**
Native School	2 (a.p. = 88%)	1 (a.p. = 61%)
Deprivation Level	Low	High
Gender	Male	Female
Number of Members	4	4

Table 6.39

Photographs of the solutions produced by Group 8 and Group 2 can be found in Appendix 18. Despite having produced very different solutions, the discussion that follows shows that, in many ways, the similarities in this dyad were greater than those evidenced in the previous three cases.

6.10.1. Set 1: Knowledge Differences

This section considers the results from the structures unit, the knowledge verbalised during the problem solving activity and that embedded within the final solutions produced by each group.

6.10.1.1. Knowledge: Attainment in Structures Unit

The overall performance of each group is given in Table 6.40.

Attainment of Groups 8 & 2 in Core Areas		
	Group 8 Score (s.d.)	**Group 2** Score (s.d.)
Overall Unit (all questions)	79% (2.89)	60% (6.11)
Core Area 1: Tension & Compression	95% (1.00)	70% (2.65)
Core Area 2: Triangulation	100% (0.00)	58% (1.26)
Core Area 3: Turning Moments	33% (2.31)	38% (0.96)
Average of Core Areas	76%	55.3%

Table 6.40

Despite the overall unit performance being 19% greater for Group 8, both groups demonstrated significant weaknesses in relation to moments. The attainment figures shown here are the lowest in the sample. Whilst Group 8 demonstrated consistent and high attainment for both forces and triangulation, the generally higher standard deviations of Group 2 suggest that understanding was comparatively more varied between group members.

6.10.1.2. Knowledge: Verbalisation During Activity

Despite levels of verbalised knowledge appearing low across the sample, comparatively fewer instances were observed in this dyad. The was no difference noted in the use of personal knowledge and, notwithstanding three counts coded in discussion with the teacher for Group 8, and one for Group 2, no knowledge of concepts or principles was verbalised throughout the activity. Differences did arise in that Group 2 verbalised more task knowledge than Group 8. Table 6.41 lists the associated counts and durations in categories where the biggest differences lay.

Overview of Verbalised Knowledge (Groups 8 & 2)		
	Task Knowledge During Construction (Incorrect-Unsure)	**Task Knowledge Prior to Construction (Correct-Sure)**
1 : Group 8 (All)	n=1, 1s	n=1, 2s
2 : Group 8 (Session 1)	n=1, 1s	n=1, 2s
3 : Group 8 (Session 2)	n=0, 0s	n=0, 0s
4 : Group 2 (All)	n=6, 15s	n=3, 11s
5 : Group 2 (Session 1)	n=6, 15s	n=3, 11s
6 : Group 2 (Session 2)	n=0, 0s	n=0, 0s

Table 6.41

Table 6.41 shows that Group 8 verbalised negligible levels of task knowledge whilst more counts of that seen with Group 2 were incorrect or unsure. As seen in previous cases, they related to uncertainly about whether certain suggestions were possible within the task. It is also noteworthy that with regard to verbalised knowledge, the similarity between these groups was the greatest for any dyad in the study.

Idea generation was coded on all four samples of structured observation for Group 8, but only on those during the first session for Group 2.

6.10.1.3. Knowledge: The Solution as Manifest Knowledge

The levels of development for both of these solutions (Group 2, n=14; Group 8, n=22) were substantially below the average for the sample (n=31.5). The solution by Group 2 exhibited very localised development with 85.7% of all developments along the road surface in Zones C and D. They were the only group not to provide structural support for the underside of the cantilever. Despite also having a low development value, a far more even distribution between zones was observed with Group 8. The configuration schematic for the solution by Group 2's, which partially failed under testing, is shown in Figure 6.22.

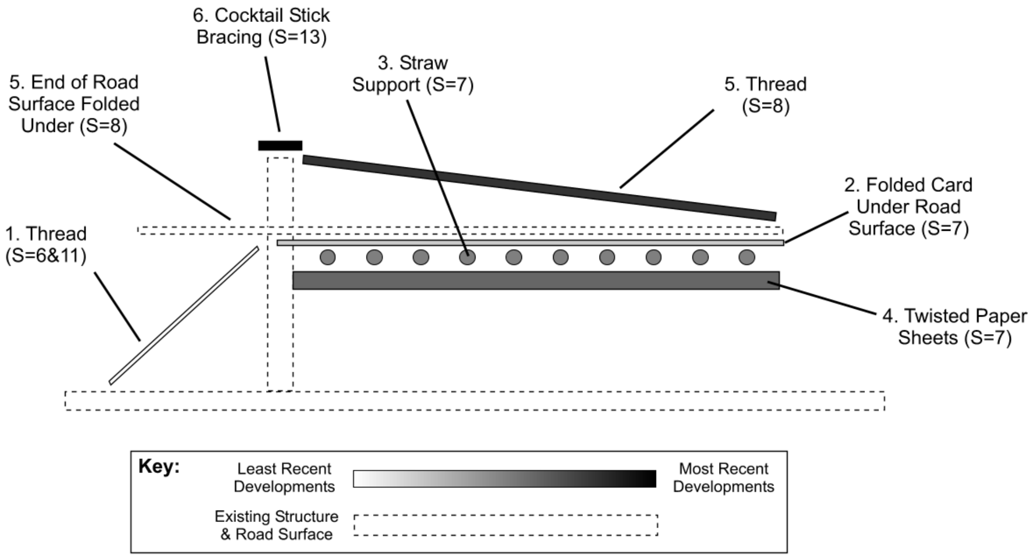


Figure 6.22 – Development of Solution by Group 2

As can be seen, of the seven core developments identified, only the initial development with thread at the rear of the bridge was redundant. Material choice and placement for the other six developments was good, however, weaknesses were identified by Delphi Experts with regard to a lack of triangulation, limited support of the road surface structure and that structure not being suitably secured to the existing frame (*see* CD-Rom: Face Validity Analysis). In some ways the solution is relatively efficient but with key weaknesses. The developments shown provide no evidence of conceptual misunderstanding and were based more around the concept of strength, than of triangulation. The failure to employ triangulation to support the underside of the road is concurrent with it not being discussed within the group. Moreover, triangulation not being shown in this capacity on any of the six sketches the group produced, may suggest that rather than being a conscious design decision, there was a failure to translate this knowledge from the structures unit into this context. Furthermore, despite being from different classes, sketches from each group, shown in Figures 6.23 and 6.24, reveal both a striking conceptual similarity and insufficient knowledge of task requirements. The structured observation noted sketching during S=1 for Group 2.

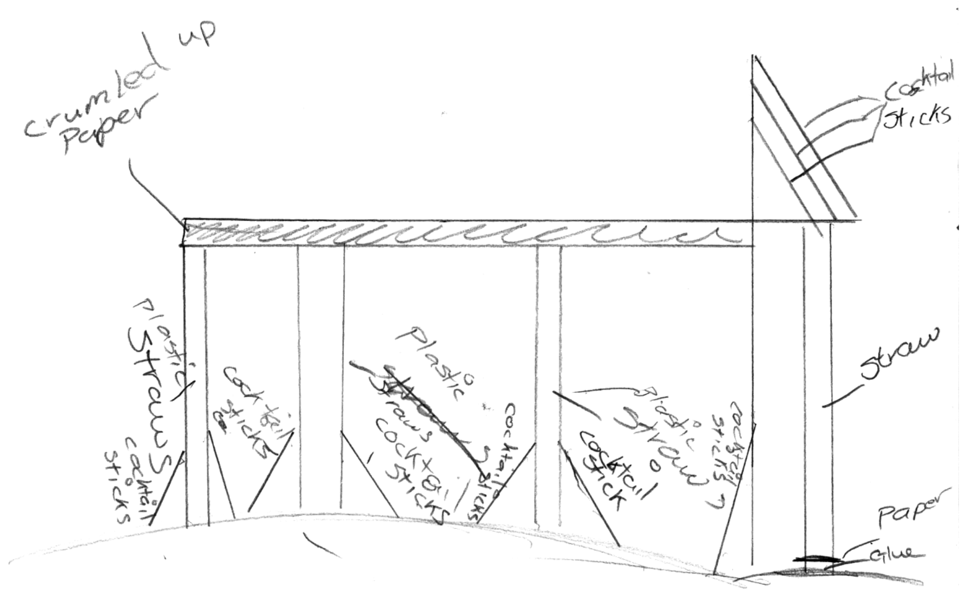


Figure 6.23 – Sketch during Conceptual Phase by Group 2

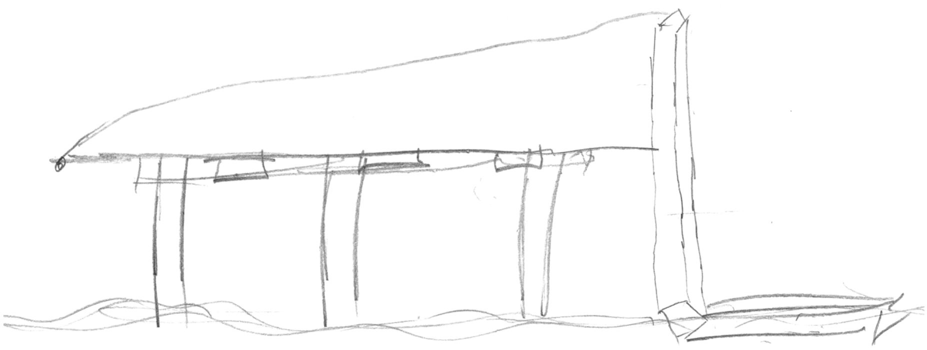


Figure 6.24 – Sketch during Conceptual Phase by Group 8

The configuration schematic for the solution by Group 8 is shown in Figure 6.25.

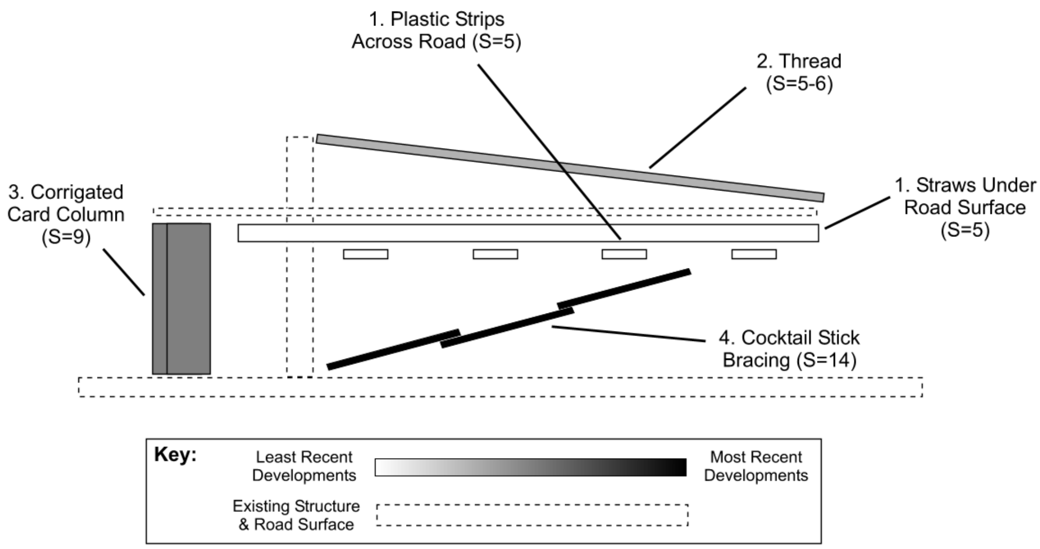


Figure 6.25 – Development of Solution by Group 8

Group 8's solution comprised the fewest number of key developments of any group in the sample. Although it ranked 4th of five groups within the class for physical testing, there was very little difference between this and the solutions higher ranking groups. This, in conjunction with the low level of development, suggests a greater level of overall efficiency in the solution. Critically, none of the developments were redundant within the structural system and, in all instances, material choice and configuration was correct in terms of the related concept or principle. This was reflected in the comments from Delphi Expert 5 who stated that, from the sample, it showed the best use of materials. As such, there was no evidence of misconception, or knowledge deficiencies, although slight weakness was present in the axial joining of the cocktail sticks.

6.10.1.4. Summary of Differences in Knowledge (Dyad 4)

1. Group 8 showed a higher level of attainment than Group 2 in the structures unit, although the attainment of both groups in relation to moments was the lowest of all dyads.
2. There was little difference in the groups' use of personal knowledge and there was almost no explicitly verbalised knowledge of concepts or principles.

3. There was no evidence of misconception within the solutions with a good overall level of knowledge of materials and forces evident.
4. There was some evidence that Group 2 failed to translate knowledge of triangulation from the unit to the task.
5. There was some evidence of a lack of task knowledge for both groups during the conceptual phase.

6.10.2. Set 2: Process Differences

This section reports on findings about the overall problem solving process as with as those difference observed in terms of management and reflection between Group 8 and 2.

6.10.2.1. Global Process: Pattern of Solution Development

The plots in Appendix 14 show that the group solutions had a characteristically different development pattern. In both cases, construction began on the road surface separately from the existing structure. Group 2 attached this during S=7 and gradually augmented it towards its final state. The development of the solution by Group 8 took place in two separate phases, towards the end of each session. Between the points, from S=10 to S=13, there was no physical change to the solution. However, findings from the structured observation shown in Figure 6.26, noted significant construction activity in Zones D and E with cocktail sticks during S=13 after which, the completed supports were attached to the main solution.

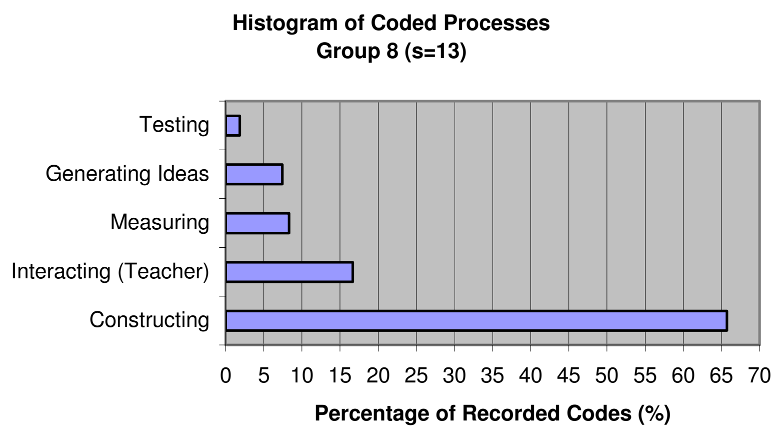


Figure 6.26 – Histogram of Observed Processes (Group 8, S=13)

6.10.2.2. Global Process: Phases of Activity

Group 2, from the poorer cohort, spent 16% longer in the practical phase than did Group 8 form the better cohort. This was similar to the findings for Dyad 2. Group 8 began construction after 7m30s and Group 2, after 8m55s. During this time, both groups are seen to engage in generating a range of initial ideas, though more so in the case of Group 8. Group 2 established a series of suggestions with input from all members which they made the decision to combine prior to construction (S=2, 1.57-2.00). Both groups established suitably discussed initial ideas and engaged in a period of sketching.

6.10.2.3. Summary of the Differences in the Global Process (Dyad 4)

1. Both groups began constructing the road structure separately and then fixed it to the structure. After this point, Group 2 steadily refined it while Group 8 constructed supports separately and added them before refining it over a shorter period.
2. Group 2 spent 1m25s longer than Group 8 in the conceptual phase.
3. Both groups established starting ideas before embarking on construction.

6.10.3. Management

Group 8 and 2 will now be compared and differences highlighted that exist with regard to group involvement, efficiency and planning.

6.10.3.1. Management: Group Involvement

With the exception of no instances of fragmented vision for Group 8, both groups exhibited evidence of all three dimension of group involvement. The greatest level of similarity lay with instances of poor group involvement, with the breakdown for each area given in Table 6.42.

As shown, fragmented vision only occurred with Group 2. This was minor and involved one pupil sticking things to the bridge for no apparent reason (S=3, 4.25-4.40). Although more counts were present with Group 8, similarities were seen in the nature of poor group involvement in regard to features of disenfranchisement and dominance (as seen with Group 7, Dyad 1). There was evidence in both groups that some pupils were not allowed to contribute to the extent they wished (e.g. Group 2, S=10, 0.06-0.11; Group 8, S=2, 1.21-

1.24); although this was more ostensible with Group 8. In a sense related, there was also a tendency for one or more pupils in Group 2 to dominate the activity (S=10, 0.06-0.11; S=2, 1.21-1.24). Not evident is the discourse of Group 8, there were also some instances in Group 2 where pupils were ignored (e.g. S=7, 0.35-0.42).

Overview of Group Involvement (Groups 8 & 2)			
	Fragmented Vision	**Poor Group Involvement**	**Roles & Tasks**
1 : Group 8 (All)	n=0, 0s	n=16, 50s	n=28, 1m09s
2 : Group 8 (Session 1)	n=0, 0s	n=15, 47s	n=20, 43s
3 : Group 8 (Session 2)	n=0, 0s	n=1, 3s	n=8, 26s
4 : Group 2 (All)	n=1, 15s	n=10, 48s	n=19, 52s
5 : Group 2 (Session 1)	n=1, 15s	n=5, 28s	n=9, 26s
6 : Group 2 (Session 2)	n=0, 0s	n=5, 20s	n=10, 26s

Table 6.42

With regard to roles and task, the evidence from Group 8 was characterised by frequently distributing aspects of a task between more than one group member (Group 8, S=1, 3.44-3.49; S=3, 1.19-1.23) and pupils taking on aspects of tasks to assist others (Group 8, S=11, 1.09-1.12). This could be seen to conflict with the evidence of poor group involvement described above; however, there was often an associated sense of compromise, especially with task distribution. Many of these characteristics were reflected in the activity of Group 2, but to a lesser degree.

6.10.3.2. Management: Increasing Efficiency

There was no discernible difference in the group's attempts to increase efficiency. Both did so on eight occasions, and most involved efforts to increase pace, however at one point, a pupil in Group 2 pulls remaining group members back onto task (S=4, 1.24-1.27).

6.10.3.3. Management: Planning

Group 8 engaged in planning for 2m17s which was 45% longer than Group 2 (t=1m15s). In all cases, measures of planning were more prevalent during the first problem solving session and things that occurred through poor planning were only coded for with Group 2. These included attempts to cut parts that were required in a different capacity (S=2, 4.41-

4.47), and including the wrong material for a given development (S=3, 4.36-4.39).

As seen with the other dyads, the planning activity that was observed was dominated by task and operation sequencing/ordering (Group 8, S=3, 0.06-0.11; Group 2, S=3, 4.18-4.22) and identifying weaknesses and requirements (Group 8, S=14, 2.01-2.08; Group 2, S=4, 0.20-0.25). The nature of this was similar for both groups but more frequent during the first sessions, and with Group 8 overall.

6.10.3.4. Summary of Differences in Management (Dyad 4)

1. Both groups displayed instances of poor group involvement though this was more significant, in frequency and nature, for Group 8.
2. Roles and tasks were allocated and distributed between members though again, the featured more with Group 8 than Group 2.
3. As with the previous two dyads, little difference was observed with process efficiency.
4. Group 8 spent almost twice as long engaged in planning processes that Group 2 and things resulting from poor planning were only coded against Group 2.

6.10.4. Process Engagement

This section reports on differences that were observed with regard to the nature of the reflection each of the group engaged with.

6.10.4.1. Process Engagement

Very little difference was noted between the nature of the reflection groups engaged with before starting to construct their solution. Both initiated 3 counts of analytical reflection, but relied more heavily upon declarative reflection (Group 8, 31s (n=12); Group 2, 22s (n=12)). Though, as shown, triangulation did not feature with Group 2, Excerpt 41 below illustrates an example of analytical reflection revealing knowledge of materials and forces. Only two counts of task reflection occurred with Group 8 and these were in relation to where they could build (S=1, 2.03-2.06) and which materials could be used (S=1, 2.39-2.45).

<u>Excerpt 41 (in reflecting on a tabled idea)</u>

"but you canny dae that straw because its no good in ehhh….. what'dy call-it… emm… compression.."
(Group 2, S=2, 1.23-1.30)

For this stage, the patterns of reflection were similar to those seen with Dyads 1 and 3, although lower than Dyad 2.

6.10.4.2. Process Engagement: Reflection During Construction

During this phase of activity, both groups were seen to engage in a significant number of reflective processes, but many more were in evidence with Group 8. 262 counts were coded (t=9m29s) compared to 134 counts (t=4m48s) for Group 2. Group 8 engaged in more reflection than any of the other groups in the cohorts, and effectively twice that of Group 2 for each identified form of reflection (task, declarative and analytical). The results are shown in Table 6.43.

Overview of Reflection During Construction (Groups 8 & 2)			
	Reflection (Analytical)	**Reflection (Declarative)**	**Reflection (Task)**
1 : Group 8 (All)	n=57, 2m43s	n=198, 6m30s	n=7, 16s
2 : Group 8 (Session 1)	n=36, 1m44s	n=95, 3m02s	n=4, 9s
3 : Group 8 (Session 2)	n=21, 59s	n=103, 3m28s	n=3, 7s
4 : Group 2 (All)	n=24, 1m14s	n=107, 3m26s	n=3, 8s
5 : Group 2 (Session 1)	n=11, 34s	n=60, 1m58s	n=2, 5s
6 : Group 2 (Session 2)	n=13, 40s	n=47s, 1m28s	n=1, 3s

Table 6.43

Table 6.43 shows that reflective processes for both groups are quite evenly distributed between each session. The use of analytical reflection by Group 8 was frequently initiated and reasoning often in a more explicit form than seen in some other groups. Typical examples of this are shown in Excerpts 42 and 43.

Excerpt 42

"..'cause see if its held there, the front bit doesny go doon and the back bit doesny go doon.."

(Group 8, S=12, 0.14-0.17)

Excerpt 43

"aye, but the string's too thin otherwise, see.. its getting through there at the end just (unclear)"

(Group 8, S=10, 1.31-1.37)

In the sense of reasoning being shared amongst group members when it is verbalised, occurrences of such explicit justification have the potential to enhance the group's overall understanding of ideas, and of the solution. Similar instances were seen with Group 2 (e.g. S=13, 1.30-1.34; S=2, 3.45-3.51), but with less frequency. The task reflection with Group 8 related to considering the legality of proposals (S=1, 1.56-1.58), as well as reflection on available materials (S=6, 3.01-3.05) and the loading conditions under which it will be tested (S=7, 0.43-0.47). Group 2 considered legality and task expectations in relation to aesthetics (S=7, 0.22-0.25). The greatest similarity in terms of the nature of reflections lay with the declarative form. Both groups made frequent use of quality assurance type assessments throughout construction.

6.10.4.3. Summary of Differences in Process Engagement

1. Group 8 initiated more reflective processes than any other group within the cohorts and around twice that of Group 2 for each type defined.
2. Although both groups undertook analytical reflection prior to construction, they both relied more heavily on declarative. Groups were very similar in terms of reflection during this phase.
3. The analytical reflection by Group 8 during construction was consistent and often explicit, though significantly greater use was made of declarative reflection.
4. Aspects of this were seen in the activity of Group 2 but to a lesser extent.

6.10.5. Set 3: Social & Extrinsic Factors

This section reports on the findings for group tension, task and study effects for Groups 2 and 8.

6.10.5.1. Social & Extrinsic Factors: Group Tension

Although elements of group tension were evident for both groups, as was seen with all previous dyads, it was far more extensive with the group from the poorer cohort, in this instance, 2. In total, 5 instances were coded for Group 8 for a total duration of 30s, whilst 18 instances were evident in the activity of Group 2 for five times as long (t=2m29s).

In the case of Group 8, group tension was largely associated with the previously identified features of poor group involvement (e.g. S=4, 0.56-1.10; S=5, 3.29-3.38), though these instances were tantamount to discontent and not as extreme as those seen with Group 4 (Dyad 3). Similarly, arguments over participation featured in the latter stages with Group 2 (e.g. S=15, 1.48-1.55), though beforehand, pupils were involved in such things as name calling (S=4, 1.10-1.15) and verbal threats (S=5, 3.00-3.07). As was the case with Group 4, activity progressed regardless of this.

6.10.5.2. Social & Extrinsic Factors: Competitive Dynamic

The findings in relation to this aspect were the most stark so far with virtually no evidence that Group 2 was affected by the task dynamic compared with effects for Group 8 that totalled 9m01s (n=42). Interestingly, this offers a more extreme reflection of the breakdown observed in dyads 2 and 3, where groups in the good cohort were far more concerned with the activity of other pupils. Table 6.44 illustrates the effects of the competitive dynamic for this dyad.

Effects of Competitive Dynamic (Groups 8 & 2)			
	Negative	**Positive**	**Neutral**
1 : Group 8 (All)	n=31, 7m21s	n=2, 6s	n=9, 1m34s
2 : Group 8 (Session 1)	n=10, 1m47s	n=0, 0s	n=5, 56s
3 : Group 8 (Session 2)	n=21, 5m34s	n=2, 6s	n=4, 38s
4 : Group 2 (All)	n=0, 0s	n=2, 4s	n=0, 0s
5 : Group 2 (Session 1)	n=0, 0s	n=1, 3s	n=0, 0s
6 : Group 2 (Session 2)	n=0, 0s	n=1, 1s	n=0, 0s

Table 6.44

The negative effects with Group 8 related exclusively to copying and occasionally mocking the solutions other groups in the class (e.g. S=7, 0.00-0.04). Most of this involved Group 7 (Dyad 1) who was the only group in the poorer cohort to exhibit more negative effects from group tension than their comparative group. This can be explained by the inter-group dynamic seen within the classroom. Though occurrences were frequent throughout the whole activity, they worsened significantly during the second session. Excerpt 44 illustrates one such typical occurrence.

Excerpt 44

Pupil (Group 8): "..oh, they're copyin' us again…. you's got the strings and the 'hings underneath the bridge.."

Pupil (Group 7): "the teacher told us ti dae that… shut-up you, right…"

Pupil (Group 8): "a.. am serious…, why-do-yi-jis.. why don't you just take ours.."

(Group 8(&7), S=16, 1.28-1.37)

As with previous dyads, neutral effects involved simply discussing the development of other group's solutions.

6.10.5.3. Social & Extrinsic Factors: Study Effects

In response to the post-task questionnaire, Group 2 reported no negative perceptions of either the tape recorder or researcher, but stated they felt that they should answer questions differently because the researcher was there. By contrast, Group 8 reported no negative or expectation effects associated with the researcher, but a negative perception of the tape recorder that they felt lessened over time. Study effects noted within the verbal data compliment much of this, however, as shown in Table 6.45, were comparatively more widespread for Group 2.

Little difference was noted in the nature of study effects observed with Group 8 in comparison to other dyads. The most considerable effect lay with the researcher effects for Group 2. Though there was no notion of these being in any way negative, one group member in particular continually attempted, throughout both sessions, to converse with and about the researcher and the researchers role (e.g. S=3, 2.21-2.47; S=13, 0.59-1.15). Despite its predominance, there was no explicit evidence to suggest this affected the group's problem solving activity.

Overview of Study Effects (Groups 8 & 2)		
	Study Effects (Researcher)	**Study Effect (Recorder)**
1 : Group 8 (All)	n=7, 34s	n=3, 35s
2 : Group 8 (Session 1)	n= 3, 16s	n=2, 21s
3 : Group 8 (Session 2)	n=4, 18s	n=1, 14s
4 : Group 2 (All)	n=15, 2m57s	n=4, 53s
5 : Group 2 (Session 1)	n=6, 1m21s	n=1, 31s
6 : Group 2 (Session 2)	n=9, 1m36s	n=3, 22s

Table 6.45

6.10.5.4. Summary of Difference in Social & Extrinsic Factors (Dyad 4)

1. Group tension featured more heavily in the activity of Group 2 than it did with Group 8.
2. Group 2 was not affected by the competitive dynamic of the task whilst, for Group 8, this was very significant. Of those instances that did occur, 74% were seen to exert an negative effect on the group.
3. Both groups exhibited effects from the researcher and recorder, although these were notably greater in the case of Group 2. These were evident for 3m50s of time within the activity and 70% of this stemmed from the presence of the researcher.

6.11. Cohort Analysis

The first stage of the analysis judged the level of ecological consistency between participating groups to be high. The second stage initially compared the groups that produced the best and poorest solutions which allowed both differences to be identified, and resultant analytical frameworks to be developed. These frameworks were then used during third stage of the analysis as a means to explore differences between the remaining dyads in rank order. In doing so, relevant similarities and differences in terms of knowledge, process and social and extrinsic factors were identified. This fourth and final analytical stage presents and summarise these results with respect to each cohort. This is done through the following stages: 'Initial Considerations'. 'Knowledge Differences', 'Process Differences' and 'Social & Extrinsic Differences'.

Findings from the cohort analysis show that, overall, the differences identified between the best and poorest groups were strongly reflected throughout the good and poor cohorts with few exceptions.

6.11.1. Initial Considerations & Assertions

The following sections clarify some provisional assertions that were necessary as a backdrop against which the findings for each cohort can be viewed.

6.11.2. The Influence of Archetype

It is necessary to recognise that the design of this study was one that established a comparative framework based upon the two most opposing cases in terms of solution: Group 5 and Group 7. As such, those groups play a definitive role. In the context of this study, these groups are considered to be pseudo-archetypal in terms of factors associated with having produced better and poorer solutions. Though the previous section demonstrated this not to be true in all instances, there is design-based methodological tendency for phenomena to be comparatively more prevalent in these two groups.

6.11.3. The Level of Task Discussion

This did not form part of the preceding stages of analysis but provides a backdrop against which to truthfully view results. While groups engaged in a significant level of discourse throughout the problem solving task, a great deal of this did not relate to the task or developing solution. In light of this, groups were also coded for meaningful, task related discussion. Herein, this is defined as discussion relating directly to the developing solution of the group in question. It excludes such things as requests to pass resources, arbitrary discussion of unrelated topics, group tension and study effects related to the researcher and recorder. The results demonstrate that groups in the good cohort discussed tasks more than those in the poor cohort. The breakdown of results is given in Table 6.46.

Duration of Meaningful Pupil Discourse by Group	
Groups	**Duration**
Group 5 (Good, Rank 1)	38m03s
Group 6 (Good, Rank 2)	26m16s
Group 12 (Good, Rank 3)	33m26s
Group 8 (Good, Rank 4)	30m13s
All Good Groups	**2h08m03s**
Group 7 (Poor, Rank 1)	31m27s
Group 13 (Poor, Rank 2)	26m26s
Group 4 (Poor, Rank 3)	25m30s
Group 2 (Poor, Rank 4)	17m09s
All Poor Groups	**1h40m32s**

Table 6.46

These results show that total amount of time spent on task discussion by the good groups was, on average, 21.5% longer than for the poor groups. Three of the four groups in the good cohort were seen to discuss for more than 30 minutes, whilst three of the four groups in the poor cohort discussed for less than 30 minutes. The respective standard deviations of 2.30 and 3.51 also reflect greater variation the durations of poorer groups. This is significant insofar as a large proportion of the differences established were embedded within group discussion.

6.11.4. Non-Profitable Omissions

Findings from the last stage of analysis revealed there was little difference or negligible counts in several areas that arose from the first analytical phase. In light of this, 'Personal Knowledge', 'Task Reflection', 'Increasing Efficiency', 'Fragmented Vision' and 'Positive Effects of Task Dynamic' will be withdrawn from further analysis.

6.12. Findings for Good & Poor Cohorts

The following sections summarise findings for each cohort. The differences in knowledge and process relate more directly to the conceptual framework than do the difference in social and extrinsic factors, many of which are due to the design of the study.

6.12.1. Knowledge: Attainment in Structures Unit

The average percentage scores from the structures unit for each cohort are shown in Table 6.47.

Overview of Cohort Performance in Core Areas		
	Good Cohort	**Poor Cohort**
Overall Unit (all questions)	83.5%	69.5%
Core Area 1: Tension& Compression	93.25%	82%
Core Area 2: Triangulation	89.75%	76.25%
Core Area 3: Turning Moments	62.25%	65.25%
Average of Core Areas	81.75%	74.5%

Table 6.47

As shown, the good cohort achieved higher overall average attainment with higher scores in two out of the three core areas. The poorer cohort had a higher average percentage score in the most conceptually demanding aspect.

6.12.2. Knowledge: Verbalisation During Activity

Table 6.48 shows the overall results for verbalised task knowledge and Table 6.49 shows the results for verbalised knowledge of concepts and principles.

Both tables show that the good cohort spent more time on explicitly verbalised knowledge than the poor cohort in categories where knowledge was correct. Though counts and/or durations were sometimes close (as in the case of incorrect/unsure task knowledge during construction), the poor cohort verbalised more knowledge that was unsure or incorrect.

The fact that the overall level of explicit verbalised knowledge is very low across both cohorts strongly suggests that much of the knowledge during problem solving was far more implicit within the process, idea generation and the developing solution itself.

Verbalisation of Explicit Task Knowledge by Cohort			
	All Groups	**Good Cohort**	**Poor Cohort**
During Construction (Correct)	n=51, 1m55s	n=28, 1m08s	n=23, 47s
During Construction (Incorrect-Unsure)	n=29, 1m02s	n=14, 32s	n=15, 30s
Prior to Construction (Correct)	n=20, 1m51s	n=9, 1m26s	n=11, 25s
Prior to Construction (Incorrect-Unsure)	n=11, 24s	n=5, 7s	n=6, 17s

Table 6.48

Verbalised Knowledge of Concepts & Principles by Cohort			
	All Groups	**Good Cohort**	**Poor Cohort**
Assisted (Correct)	n=32, 1m21s	n=20, 45s	n=12, 36s
Assisted (Incorrect-Unsure)	n=11, 20s	n=4, 11s	n=7, 9s
Independent (Correct)	n=32, 1m27s	n=20, 56s	n=12, 31s
Independent (Incorrect-Unsure)	n=7, 19s	n=1, 2s	n=6, 17s

Table 6.49

6.12.3. Knowledge: The Solution as Manifest Knowledge

The differences evident between the solutions of groups and the related knowledge was not always of a form as readily quantifiable as other dimensions of the problem solving task; though differences were present nonetheless. In the broadest sense, however, the evidence presented suggests that most differences were in the form of knowledge deficits.

All bar one of the groups in the poor cohort exhibited comparatively low build quality. It is recognised that a range of factors affects this and that isolating them is essentially not possible. However, this suggests that, overall, the poor cohort had a lower level of tacit-procedural knowledge than the good cohort did.

Both cohorts were seen to include developments that offered little functional advantage to the developing solution. Significantly, however, it was only within the poor cohort that selected developments were the direct cause of lower functional performance within the structural systems. Depending upon how this was viewed, it could be as a result of poor material choice/configuration, or a lack of appropriate measures to bolster the weaknesses. Given that the poor cohort did very well in the tension and compression section of the unit (82%), which involved testing the performance of a range of materials under different loading, it suggests there were specific areas of difficulty in translating this knowledge into the context of the developing solution. This issue of knowledge transfer may also account for the partial omission of triangulation seen in Dyad 4.

Ultimately, this could result from a lower level of knowledge and understanding about how the solution works as a complete system. This was most evident with Group 4 (Dyad 3) who was seen to construct a series of largely discrete developments. It was, however, out with the scope of the data set to find explicit corroborative evidence of this.

6.12.4. Global Processes: Pattern of Solution Development

Though differences were evidence in the patterns of development for each group, none were identified as consistent for each cohort.

6.12.5. Global Processes: Phases of Activity

Overall statistics show that the good cohort spent, on average, 18% longer in the conceptual phase than the poor cohort did. The average duration for the good cohort was 9m50s (s.d. 1.11) and 8m04s for the poor cohort (s.d. 2.73). The difference between the average times was 1m46s. All groups managed to generate suitable initial ideas with the exception of Group 7 and Group 4, both from the poor cohort.

6.12.6. Differences in Process Management

Table 6.50 lists all of the differences observed in terms of the management factors identified.

Management of Problem Solving Process by Cohort			
	All Groups	**Good Cohort**	**Poor Cohort**
Group Involvement (Poor) (-)	n=77, 4m53s	n=18, 1m09s	n=59, 3m44s
Group Involvement (Roles & Tasks) (+)	n=172, 7m45s	n=109, 5m16s	n=63, 2m29s
Planning, Sequencing or Identifying Requirements (+)	n=258, 23m21s	n=159, 15m35s	n=99, 7m46s
Results of Poor Planning (-)*	n=26, 2m02s	n=7, 19s	n=19, 1m43s
Negative Management Traits	n=102, 6m55s	n=25, 1m28s	n=77, 5m27s
Positive Management Traits	n=407, 30m29s	n=252, 20m26s	n=155, 10m03s

*Durations are given although these counts relate to events and not to processes.

Table 6.50

It shows that overall, the good cohort engaged in positive management traits for around twice as long as the poor cohort did. As was seen with the verbalisation of knowledge, the opposite is also seen in that the poor cohort exhibited more negative traits. The biggest proportional difference lay in the counts of things resulting from poor planning, 73%. For time-based measure, the biggest proportional difference was found in poor group involvement (72%) with the remaining differences for measures of roles & tasks and for planning were 53% and 45% respectively. Overall, this shows that though they differed on all counts, they differed more with regard to negative factors.

6.12.7. Differences in Process Engagement

Similarly to most previous measures, the data indicate that reflection was more prominent with the good cohort in three out of four measures. Overall, the good cohort engaged in reflective processes for 38% longer than did the poor cohort.

Table 6.51 shows that the good cohort undertook more analytical reflection than the poor cohort in all phases with the biggest proportional time difference in analytical reflection prior to construction (59%). A similar difference of 56% is seen with analytical reflection during construction whilst the least difference was with declarative reflection prior to construction (4.3%). Notwithstanding the fact that more reflection was undertaken by the good cohort, the principal difference was in terms of analytical reflection. Not only is this empirical evidence that pupils were engaging more deeply with processes, but it also meant that this understanding was more available to pupils in the good cohort than it was for pupils in the poor cohort. In this sense, the findings here are also significant for the knowledge dimension of group activity.

Process Engagement by Cohort: Reflection			
	All Groups	**Good Cohort**	**Poor Cohort**
Analytical Reflection (Prior to Construction)	n=49, 2m36s	n=34, 1m51s	n=15, 45s
Analytical Reflection (During Construction)	n=336, 16m55s	n=231, 11m45s	n=105, 5m10s
Declarative Reflection (Prior to Construction)	n=119, 3m47s	n=54, 1m51s	n=65, 1m56s
Declarative Reflection (During Construction)	n=1056, 32m38s	n=611, 19m	n=445, 13m37s

Table 6.51

6.12.8. Differences in Social & Extrinsic Factors

The results for social and extrinsic differences were more mixed than those found with other measured. Table 6.52 lists these for each cohort.

Social & Extrinsic Factors by Cohort			
	All Groups	**Good Cohort**	**Poor Cohort**
Group Tension	n=116, 12m23s	n=11, 1m04s	n=105, 11m19s
Competitive Dynamic (-)	n=108, 15m58s	n=69, 11m35s	n=39, 4m23s
Competitive Dynamic (n)	n=37, 5m19s	n=28, 4m15s	n=9, 1m03s
Study Effects (Recorder)	n=67, 9m53s	n=23, 2m32s	n=44, 7m21s
Study Effects (Researcher)	n=50, 5m52s	n=20, 1m37s	n=30, 4m14s

Table 6.52

Two distinct groups of findings are shown here. Firstly, that the poor cohort exhibited significantly more group tension and were far more affected by the study than those groups in the good cohort. An overall time difference of 91% meant that differences in group tension were the most significant of all measures in the study. Percentage time differences for each of the study effects were similar: 65% for recorder effects and 62% in terms of researcher effects. Secondly, in the context of the preceding sections of the analysis, increased group tension is not unexpected for groups exhibiting significantly poorer management traits; however, the degree to which groups in the good cohort were affected by the competitive dynamic was more distinct. The good cohort exhibited significantly more negative and neutral effects from the task structure than the poor cohort did. The percentage time differences were 62% and 75% respectively. Of those themes and measures explored, this represents the only difference that opposes that found in the initial comparison of Groups 5 and 7.

6.13. Gender & Task Performance

Though not a core focus of this study, the gender balance between the good and poor cohorts was quite distinct. 3 of the 4 groups in the good cohort were female, whilst three of the four groups in the poor cohort were male. As such, it could be argued that many of the factors associated with more successful problem solving were more prominent with girls than with boys.

6.14. Summary of Overall Differences between Cohorts

There were a range of measures along which differences were observed between the good and poor cohorts. On average, groups in the good cohort talked directly about the task for a greater length of time and spent 18% longer in the conceptual phase of problem solving activity. They exhibited more positive management traits whilst those groups in the poorer cohort exhibited more negative traits. The overall level of reflection for the good cohort was greater, with respect to both declarative and analytical forms. Finally, the biggest difference was that the total duration of group tension within poor groups was 91% greater than that of good groups and although poor groups were more affected by the researcher and recorder, the effects of the competitive task dynamic were significantly greater with good groups.

Chapter Seven

Discussion & Conclusions

7. Discussion & Conclusions

This study develops a conceptual framework for classroom-based technological problem solving and explores the differences between high and low performing groups by comparing their problem solving activity in terms of knowledge and processes. Specifically, the study investigates the following research question:

'In terms of intellectual processes and knowledge, what are the differences in the modi operandi between groups of pupils that produced more and less successful technological solutions to a well-defined problem?'

In answering this question, the analysis undertaken in the previous chapter identifies nine core areas in which differences lay. Overall, it was found that groups in the higher performing cohort:

1. Engage in more task-related discussion.
2. Verbalise more objective knowledge with fewer deficits evident in the final artefact.
3. Demonstrate a higher level of tacit-procedural knowledge.
4. Spend longer in the conceptual phase of problem solving, prior to commencing construction.
5. Utilise more positive managerial traits and fewer negative managerial traits.
6. Engage in more reflection and, specifically, more analytical reflection.
7. Exhibit considerably lower levels of tension between group members.
8. Are significantly more affected by the competitive task dynamic.
9. Are not as affected by influences from the study itself.

As shown in the proceeding section, there are a range of studies that report on elements of these findings, however, the unique and significant contribution of this study is that it clearly demonstrates that each has a tangible role in shaping pupils' success when undertaking technological problem solving.

7.1. Contributions made by this Study

In many instances, this study augments the findings from other, previous studies by demonstrating the existence, or otherwise, of their findings in the context of group-based technological problem solving. This offers a valuable contribution to the collective understanding within the field of technology education research; however, the study also empirically defines the concepts of 'declarative' and 'analytical' reflection. The author considers these concepts to be the most original and significant contribution made by this thesis.

The following sections consider each of the findings against existing research, and identify the contributions of this study. These are also mapped back to the requisite parts of the conceptual model of technological problem solving presented at the end of Chapter 2 (Figure 2.14). It should be acknowledged that there is lack of research associated with some of these in the field of technology education, and studies from wider educational research are drawn upon during the discussion. This chapter concludes by specifically identifying the study's key strengths, limitations and areas for future research.

7.1.1. Finding 1: *The higher performing cohort engage in more task-related discussion.*

Significantly, this reflects findings by Bennett & Cass (1989) who, in comparing a range of pupils groups report that, in all instances, higher attaining groups talked more than lower attaining groups (*see also* Glass, 1990). Webb (1983), however, cautioned against the risk of weak relationships to performance by simple frequencies of utterance that do not consider the nature of what is said. Notably, this risk is mitigated within this study which showed that this increased level of discussion also accompanies an increased level of reflection. Indeed, Hendley & Lyle (1995), argued that class discussion is crucial in developing technological skills, including reflection, and Hennessey & Murphy (1999), argued that 'productive thinking' is reflected in and stimulated by pupils' discussion when sharing and assessing ideas.

This study shows these findings are supported within the context of small-group technological problem solving and highlights the importance of teachers working with pupils to enable and promote high quality and considered discussion during group-based technological problem solving. Mercer (1996), argued pupils often do not know how to naturally take advantage of such discussion. As seen herein, increased levels of discussion provide a significant vehicle for many of the key processes which are ultimately manifest within pupils' discourse.

7.1.2. Finding 2: *The higher performing cohort verbalised more objective knowledge with fewer knowledge deficits evident in the final artefact.*

It is shown that there are instances where groups within the poorer cohort do not transfer prior knowledge to the problem solving task as comprehensively as those in the good cohort. This difficulty found in translating learning from one context to another has been widely recognised in Situated Cognition (Lave & Wenger, 1991), General Cognition, Intelligence (Detterman, 1993) and Education (Perkins & Salomon, 1998). Moreover, McCormick (2004) discussed instances of this specifically within technology classrooms where even a slight shift in context can result in a failure to transfer understanding.

Though the overall level of verbalised knowledge was low, this study suggests that pupils within better performing groups have a slightly greater propensity to draw upon it. More significantly, however, the deficits that are observed in some of the solutions within the poorer cohort, provide examples of this difficulty arising when the source context is conceptual and the target context is physical; a transitive pathway arguably central to technological problem solving. Whilst acknowledging the relatively small sample size used within this study, the findings still suggest that the more effective and comprehensive the conceptual-practical translation, the greater the functional performance of the technological solution. With regard to the conceptual model presented in Chapter 2, this finding suggests that there are remarkably few instances in which objective knowledge from the various sources (conceptual and that of principles and relationships) are utilised in the application block for this particular task (*see* Figure 2.14).

7.1.3. Finding 3: *The higher-performing cohort demonstrates a higher level of tacit-procedural knowledge within the final artefact.*

Understood to be implicit within activity and evidenced in the final artefacts, this essentially is the result of an individual's judgement, skill and practice (Polanyi, 1967). Closely related to how well the solution has been constructed, and on a neurological level, this is also closely tied to an individual's fine motor skills. Variations can be explained by Welch (1998), who stated that pupils bring prior tacit knowledge about how to design and construct technological solutions much of which derives from experiences through play and interaction with materials and the environment (*also see* Schön 1983). Indeed, the importance of developing this capacity for groups such as those in the poorer cohort is underscored by Losse et al (1991), who argued that poor fine motor skills can prevent pupils engaging fully with subjects such as Technology.

Evidence from this study confirms that tacit-procedural differences play a role in how well groups are able to develop a functional, technological solution. The epistemological model presented in Chapter 2, suggests the continued re-application of skills and knowledge towards a practical end builds up such procedural knowledge which, with experience, would become more implicit or tacit (*see* Figure 2.14). Though findings herein also suggest, as Welch (1998) does, that it is necessary to identify, with greater specificity, those skills that enhance pupils' abilities to externalise ideas and establish when they should be taught.

7.1.4. Finding 4: *The higher-performing cohort spends longer in the conceptual phase of problem solving.*

Within the conceptual framework of this study, it is acknowledged that a pupil who is a novice designer has a tendency to move to the practical phase prematurely (Anning 1994). This is observed for some groups and not for others. Gustafson & Rowell (1998) report that, children of 10-13 years of age are more willing to plan longer than younger children during this initial phase but findings from this study further add that there can be performance benefits associated with the increased time duration before establishing a starting point, even though McCormick et al (1994), noted that in a design task studied, much of the initial planning failed to appear in later stages of the process. Though the reasons why some groups move more rapidly to the practical phase in this study are unknown, it does constitute a more reactive approach to problem solving insofar as this planning becomes more integrated with the active development of the solution. This could be the result of a pre-existing preference, the like of which is suggested by Gustafson & Rowell (1998), or that pupils see less value in this conceptual aspect in the context of the task as whole.

7.1.5. Finding 5: *The higher performing cohort utilises more positive managerial traits and fewer negative managerial traits.*

Research in this area is split between studies exploring pupils' in-task management processes and those that explore the ways in which teachers manage learning in group tasks. Most studies appear to investigate the latter but this study primarily contributes to the understanding of the former, as management is recognised within the conceptual framework as an intellectual process of technological problem solving. Within the conceptual model of problem solving presented in Chapter 2, management is one of a range of processes that were defined within the application block (*see* Figure 2.14). The following findings identify it as one in which key differences are seen in relation to task performance.

Role & Task Allocation & Adoption

Rowell (2002), described how pupil dyads, engaged in technological activity, constructed social roles and roles based upon operational identities. Not only does this study demonstrate such roles to be present within larger group problem solving, but develops this through evidence that higher performing groups naturally make greater use of such roles than do lower-performing groups. Rowell also discussed the fact that task participation was mediated by tools and varying degrees of willingness by pupils to utilise these. This is also seen within this study with instances of task participation based upon pupils actual or perceived skill sets.

Planning

Gustafson & Rowell (1998), noted that studies considered planning as either a global problem solving process in itself, or as a sub-process within a larger problem solving endeavour. This study offers evidence regarding apparent differences in the latter. Hennessey & Murphy (1999), asserted that pupils' procedural planning for making was usually short-term and incremental, and further made the distinction between this and conceptual planning during design phases. They also stated that Baker-Sennett et al (1993), argue that the most successful planning included a combination of advanced planning and improvisation. Firstly, this study shows evidence of both procedural and conceptual planning. Secondly, though all groups utilise improvisational planning throughout, increased levels of discrete, advanced planning by the higher performing cohort support the aforementioned benefits of combining each.

Poor Group Involvement

A range of key effects have been identified by other studies that can explain poor group involvement. 'Social loafing' involves lessening effort by one member in the knowledge that this can be masked in the overall group (Harkins, 1987). Salomon & Globerson (1989) defined the 'freerider effect', the 'sucker effect' and 'status differential effects'. The first of these is the inverse of social loafing, while the sucker effect describes a pupil reducing their effort based on the perception they are being left to do everything. Lastly, status differential effects are seen to arise due the perceptions members have of each other and can result in 'higher status' individuals dominating group activity and becoming communication centres. Aspects of these are evident to differing degrees throughout all groups within the study and shows that they are more prominent with lower performing groups.

7.1.6. Finding 6: *The higher-performing cohort engages in more reflection and, specifically, in more analytical reflection.*

Through empirically defining the concepts of declarative and analytical reflection, this study is able to show that higher performing groups verbalise reasoning to a greater degree than lower performing groups; making it a shared commodity between members. Indeed, Paterson et al (1981), argued that higher ability pupils have a greater propensity to engage in general reflective behaviours in a group setting; something seen within this study. Webb (1982), reported that pupils within small groups who offered explanations demonstrated a higher level of achievement than those who did not engage as actively with these processes. Maybin (1994) reported a greater tendency for children to do this informally, out with the classroom.

The above evidence suggests a link between reflection and ability which this study develops in two distinct ways. Firstly, it is able to show that this association holds true for small-group technological problem solving, and centralises the importance of developing pupils' skills in reflection in this context. Secondly, it is able to define two functionally distinct levels of in-task reflection for technological problem solving providing a robust basis from which the design of more targeted pedagogical approaches can be considered. Specifically considering evidence in relation to performance provides a strong case for promoting pupil's skills and abilities in using analytical reflection at key points in the solving process. This has the potential to raise the quality of the technological solution and promote deeper collective understanding of the technological concepts involved.

Within the conceptual model of problem solving in Chapter 2, reflection is understood to be part of a range of the processes identified by Halfin (1987) and others. Along with 'Management' this study shows the reflection (and the nature thereof) to be a key process within the application block where differences can be associated with task performance. More significantly, however, the instances of analytical reflection within this study provide evidence that the higher performing cohort is engaging with a greater depth of explanation as associated with the upper stratum of knowledge (declarative reflection being more closely tied to the lower stratum and shallower levels of explanation). Much of this reflection is also tied to the developing solution and is seen as a function of re-application (*See* Figure 2.14).

7.1.7. Finding 7: *The higher performing cohort exhibits considerably lower levels of tension between group members.*

There is notably little research on the role of tension between pupils in small groups with most research exploring this within wider social contexts such as race, class, gender and religion. That being said, Johnson et al (1992), reported that pupils appear to have the ability to resolve conflict within groups, even when adult intervention fails to do so and it is noted in a range of studies (e.g. Niaz, 1995), that Piaget's concept of 'cognitive conflict' can have a positive influence on task outcomes. However, this is not true within this study as much of the tension results from negative managerial traits such as poor group involvement. The fact that tension was so high with lower performing groups reiterates the need for pupils to improve their understanding and use of strategies that better manage the problem solving process.

Significantly, this study clearly identifies a range of managerial characteristics in technological problem solving associated with high and low performing pupil groups. In general, those traits within the higher performing cohort are characteristically more 'proactive' than those seen in the poorer groups.

7.1.8. Finding 8: *The higher performing cohort is significantly more affected by the competitive task dynamic.*

Sherif et al (1961), asserted that inter-group conflict in competitive contexts can actually serve to promote in-group favouritism and was able to show it not to be a determining factor of competition outcomes. Erer et al (1993) have shown that inter-group competition can mitigate the aforementioned 'freerider effect' which may mean there is potential to increase pupils' contributions to group activity. Though such instances are coded to be negative within this study, these studies, and the fact it is the high performing groups that are overwhelmingly affected by this, suggest the effect may actually be beneficial to the groups' solutions.

7.1.9. Finding 9: *The higher performing cohort is not as affected by influences from the study itself.*

The theoretical considerations surrounding study effects are comprehensively discussed in Chapters 4 and 5 and the temporal acclimatisation planned for is evident in almost all cases; as also found by Measor & Woods (in Wallford, 1991). Specific reasons for the overall prominence of study effects within the poorer cohort are out with the scope of this study.

7.2. Recommendations for Teaching & Learning

The demonstrated ecological validity and natural setting of this study means that even though the sample is not extensive, it is still possible to make recommendations for teaching and learning, as distinct from claims of a broad generalisation of findings. The following recommendations relate to four dimensions to which the individual findings can be seen to relate. These are 'knowledge transfer', 'tacit-procedural knowledge', 'process management' and 'the nature and use of reflection'. It is noted that although this study focusses upon technological problem solving, some aspects of these recommendations may also inform on related wider educational settings and subjects.

7.2.1. Recommendation 1 (Knowledge Transfer)

Pupils should be given opportunities to develop explicit skills in conceptual-conceptual and conceptual-practical knowledge transfer. This could be taught discretely, done as part of an initial analytical phase in problem solving but must be experienced and taught within construction and development phases. By its very nature, technology demands that knowledge and understanding be drawn from a range of sources and applied towards a functional end. Within technology education, as in many other areas, this will necessary involve instances of near and far-transfer (*see* Hyde et al, 2009). Perkins & Solomon (1992), defined 'low road transfer' and 'high road transfer' respectively and suggested that to encourage the latter, pupils need to consciously employ a search strategy.

7.2.2. Recommendation 2 (Tacit-Procedural Knowledge)

Pupils should be given opportunities to manipulate, configure and join a range of materials using a range of methods within functional constraints where there is a focus upon the accuracy and quality of construction in both primary and secondary school. Studies have shown that motor skills can be developed through specific classroom activities (Rule & Stewart, 2002) and things such as learning to play an instrument (Hyde et al, 2009). Neurological studies, however, have indicated that the developmental window for pupil's fine motor skills is most prominent up to, and narrows beyond, around 10 years of age (Frossberg, 2000).

7.2.3. Recommendation 3 (Process Management)

Pupils should develop specific knowledge of, and skills in, the use and allocation of roles and tasks and develop and awareness of when to employ more discrete, prior planning; especially during the construction and development phase. In many senses, this will rely quite heavily upon building both strategic knowledge associated with navigating the changing demands of the solution as well as the social knowledge and skills to ensure any elevated levels of tension are mitigated.

7.2.4. Recommendation 4 (Nature & Use of Reflection)

Pupils should develop skills in using analytical reflection during group-based technological problem solving to promote deeper collective understanding and increase the chance of raising overall task performance through more refined and considered idea generation. Pedagogical approaches should endeavour to build up pupils skills in assessing 'why' as well as 'what' during evaluation-modification cycles.

7.3. Strengths of this Study

In addition to the findings themselves, a number of key strengths are identified.

1. The design of the problem-solving task is highly suited to exploring the aspects of the conceptual model for technological problem solving within the conceptual framework.

2. The inductive dimension within the design of this study allows for elements of theory generation to emerge rather than just exploring existing knowledge against a different population.

3. The core data used within the study is primary by nature in that it stemmed directly from the task and not from perceptions or accounts thereof. The group situation elicits a rich source of discourse (as was predicted by Blatchford et al, 2006) with no need for pupils to utilise verbal protocols. Moreover, this 'closeness' to the phenomena of interest is maintained through analysing the raw audio data, rather than verbal transcripts.

4. The range and nature of data sources allows for the generation of a very detailed composite representation of pupils problem solving activity.

5. The development of bespoke approaches affords a robust, reliable and detailed analysis of physical solutions.

6. The volume of data within the study, and the level at which it is analysed, bolsters the overall reliability of the knowledge claims made.

7. The study is naturalistic and carried out within real classrooms thus enhancing the relevance of arising implications to the teaching of technology to pupils.

7.4. Limitations of this Study

1. Although important differences between less and more successful groups are clearly identified, it is out with the scope of this study to ascertain the extent to which these factors can act as predictors of task performance.

2. It is out with the scope of this study to determine the degree to which each of the factors it identifies affects overall task performance.

3. Although all possible measures are taken to maximise transferability within the constraints of this study, the sample size, and nature of the chosen problem are insufficient to claim that these findings apply to technological problem solving in all classrooms.

7.5. Areas of Further Research & Development

The following areas are identified for further research that might add to or enhance the contributions of this study.

1. Exploring ways in which the reflective, managerial and knowledge transfer findings can inform pedagogy (and associated assessment approaches) for the purposes of enhancing pupil performance in similar types of learning situations. In line with the recommendations, this involves exploring the extent to which the skills and knowledge deficits associated with the poorer groups could be taught and enhanced.

2. Investigate the interrelatedness of the salient features of activity identified. Does any one determine the extent of another, or is one notably more significant than the others?

3. Examining the extent to which the factors identified might act as predictors of task performance.

7.6. Closing Comments

This study presents significant findings associated with difference in group performance for pupils undertaking technological problem solving. It is hoped that these can provide a basis for exploring effective and refined approaches to increasing pupils' technological capability in this context.

Appendix 1
Unformatted Information for Teachers

Short Course – Bridges

Overview of Course
This short course will be used to gather data on the knowledge and processes used by pupils during technological problem solving. The course should last four to five periods in total and consists of two single lesson periods and two periods in which pupils will have the chance to design and construct a cantilever arm in solution to a given problem. Detail of the course content for each of these sections is given in the following pages.

Timing
It is recognised that schools operate different timetables and that the length of periods may vary between schools. The lesson plans are designed to take up about a fifty minute period, however, will have to be taught quite quickly. They are intended to ensure pupils do not finish early. Timing during the first two lessons in this course is not critical. It may be that it is more suitable to break the content across three periods if possible. The time allocated for the problem-solving task should be as consistent as possible between schools.

Resources
All of the resources necessary for teaching this unit of work will be supplied. This includes, for example, worksheets, demonstration models, glues, card, and plastic.

Teaching of the Unit
This pack is in no way dictating the manner in which a teacher should teach the unit to the class. It is highly desired that the teacher takes this unit of work and teaches the way they would under any other circumstances - it should be as normal to the pupils in the respect as possible. It is quite important, however, that the teacher delivers all of the content outlined in the unit and refrain from adding or taking away from this. It is important that the pupils between the participating schools are exposed to the same knowledge and contexts prior to undertaking the design and make task.

Pupils Task Sheets
All the necessary task sheets are provided and pupils should complete their work in pen. This not only enables their responses to be scanned as data, but also shows whether or not they have amended previous answers.

Lesson One: Types of Bridges and Forces

Overview
This lesson is intended to introduce pupils to bridges as a form of structure, the types of bridges that there are and the role of compression and tension in bridges.

Outcomes
By the end of the lesson, pupils should be able to:

1. Describe the three basic forms of bridge (beam, arch & suspension).

Here, pupils should be able to visually identify the three basic forms of bridge. They should be able to describe the distinct features of each bridge (why they are named as they are) and should have an idea about the strength and rough relative sizes of these bridges:

Arch is very strong but does not normally span a huge distance. Often several arches together are used to achieve this (e.g. viaduct).

Beam Bridge is generally the weakest form of bridge because it is not as well supported as the others. Tends also to span the smallest distances as a result.

Suspension bridge is generally much larger than the other bridges spanning a gap of up to 2km. Suspension bridges can also support a lot of weight (consider all the cars crossing the forth road bridge).

2. Explain what 'compression' and 'tension' mean, and identify where these may act in each of the three forms of bridge.

Pupils should be able to tension as a force that tries to pull things apart. Examples such as tug-of-war, where the rope is said to be 'in tension'.

Pupils should be able to define compression as a force that tries to squash things. Examples such as the seats they are sitting on, where, due to their own weight, the seat can be said to be 'in compression'.

After exploring these forces in the beam bridge as a class (including the compression and tension of the deck), Pupils should be able to mark on a basic suspension bridge the elements that they think are in tension and those they think are in compression.

Assessment

For the above outcomes:

1. Pupils will complete a task sheet requiring them to draw and describe each type of bridge (pupils work individually; task sheets will be supplied).

2. Pupils will complete a task sheet to give the definition of tension and compression, list materials that are good in tension/compression and give an example of tension and compression in a suspension bridge.

Activities
For outcome 1, the class is taught as a whole and pupils complete task sheets individually.

For outcome two, after exploring compression and tension, the pupils, in groups of two, will be given a range materials and should decide whether the material performs well in tension or compression. They should complete their task sheets as they progress.

Differentiation
It is important that differentiation only takes place formatively during teaching and is not used in the form of extra work or examining concepts in more depth. This would invalidate the sample.

Suggested Order of Lesson

1	**Teacher:** Introduction (not too long)	E.g. What are bridges? What do they do? Naming bridges they know etc...
2	**Teacher:** Types of Bridges	Introduce Beam, Arch and Suspension bridge (Posters provided)
3	**Pupils:** Task (working individually)	Complete task sheet on types of bridge.
4	**Teacher:** How bridges work	Must be designed to withstand many different forces (wind, snow, vehicles) Introduce tension and compression
5	**Pupils:** Task (working individually) **Pupils:** Activity (in groups of two)	Pupils define compression and tension (task sheet provided). Pupils explore materials for tension and compression. They complete the task sheet as the go.
6	**Teacher:** Tension and Compression in bridges	Work through example with whole class using simple beam bridge. Introduce Member in compression = strut, member in tension = tie.
7	**Pupils:** Task (working individually)	Complete task sheet to identify tension and compression in a suspension bridge.

Whilst it be felt that it is more suitable to teach these sections in a different order, it would be better if this was followed to allow for consistency between schools.

Lesson Two

Triangulation and Cantilevers

Overview
This lesson is intended to introduce pupils to the concepts of triangulation and rigidity in structures as well as look at turning moments through a case study of a cantilever bridge.

Outcomes
By the end of the lesson, pupils should be able to:

1. Describe ways in which triangulation affects the rigidity and overall strength of a structure.

Here, they should know that a structure is likely to move and would be less stable where there is no triangulation used. Triangulation should be seen as a technique for making structures stronger and more rigid.

2. Describe what is meant by the term 'turning moment' and how it affects the cantilever arm of a bridge.

Here, pupils should not be told about moments in a mathematical sense (i.e. F x D), but rather should know that a turning moment is a force that tends to make something rotate about a point; the further away the force is from that point, the greater the turning force. This can be demonstrated well with the model provided. The knowledge that the further away from the turning point you get, the greater the turning force represents the 'knowledge of principles' element within the study.

Pupils should be introduced to the cantilever through looking at a cantilever bridge (sheets supplied). They should be able to define a cantilever arm simply as a lever that is fixed at one end. Included, are visual examples of cantilever bridges consisting normally of two cantilever arms.

Assessment

For the above outcomes:
1. Pupils will work in groups of two with the small kit provided to explore triangulation and complete the task sheet as they progress *(The kit will consist of five plastic members, four of which will be shorter than the fifth and fastening pins for connection of each).*

2. Individually, pupils should complete the task sheet where they define both a cantilever and turning moment as well as mark down the turning effects on a cantilever diagram.

Activities
For outcome 1, after the class has been introduced to triangulation, the pupils, in groups of two, work through the activity sheet with the kit provided and evaluate the rigidity and stability of several frame structures.

For outcome 2, the class is taught as a whole and pupils complete task sheets individually.

Differentiation
It is important that differentiation only takes place formatively during teaching and is not used in the form of extra work or examining concepts in more depth. This would invalidate the sample.

Suggested Order of Lesson

1	**Teacher:** Introduces Triangulation	Triangulation in nature - human body more stable if legs wider apart, trees etc..
2	**Pupils:** Activity (in groups of two)	Work through task sheet with kit provided and complete answers as they progress.
3	**Teacher:** Introduce Case Study (Special type of bridge : cantilever)	Describes the concept of a cantilever bridge constructed from two cantilever arms.
4	**Teacher:** Introduces turning moments on the cantilever bridge	A good method is to consider what happens as a car drives over the bridge. This can be aided greatly using the model provided.
5	**Pupils:** Task (working individually)	Pupils complete task sheet and describe firstly what a cantilever arm is, and then what a cantilever bridge is. Pupils describe what a turning moment is and mark its effects on the diagram provided.
6	**Teacher:** Brief Recap of the elements covered.	

Whilst it be felt that it is more suitable to teach these sections in a different order, its would be better if this was followed to allow for consistency between schools.

Lessons 3 & 4

Design & Make Task

Overview

This section forms the design and make activity and is the period during which data will be gathered on the strategies and knowledge of the pupils. Pupils will be given a problem whereby they are required to design and make a cantilever arm strong enough to support a mass (e.g. toy car) at three points along the deck.

Pupils will be given a period of time (e.g. 15-20) minutes to sketch down design ideas and decide on a suitable way forward. After this, they should begin construction.

For this activity, it is important that every effort be made so that pupils work in single-sex groups of four. It is recognised that this is not normal classroom practice, however, there is a far greater tendency for pupils to converse within groups using this arrangement. The conversations, which will be recorded, form an integral part of the data gathered.

Pupils will be given two different resources to help them design and construct the cantilever arm: (1) a box of selected materials and resources which is the same for every group in the experiment, and (2) a base and deck around which they can construct their model.

The resource box will contain items such glue and tape as well as the material out of which the model should be constructed.

The base will be constructed from MDF with two pillars set at the turning point of the cantilever arm. The deck will be cut to fit this, however, will be far too thin to support its own weight. It will be necessary for the pupils to make the deck rigid, support it in some way for the mass and fix it at one end.

The finished models will be tested.

Appendix 2
Pupil Task Sheets 1 &2

S2 - Bridges *Name:* ______________________

Bridge 1

In the spaces provided below, quickly name and sketch the three types of bridges.

This is a sketch of ______________________.

Bridge 2

This is a sketch of ______________________.

Bridge 3

This is a sketch of ______________________.

S2 - Bridges *Name:* ______________________

Part 1 Compression & Tension

Complete the following sentences to describe compression and tension.

(1) Compression is ______________________

____

(2) Tension is ______________________

____

Part 2 Materials in Compression and Tension

Using the different materials you have been given, complete the following table to describe how well materials work under tension and under compression.

You should name the material, test the material, and tick the appropriate boxes. The first one has been done as an example.

Name of Material	Good in Compression	Bad in Compression	Good in Tension	Bad in Tension

Appendix 2
Pupil Task Sheets 3 & 4

S2 - Bridges *Name:* ______________________

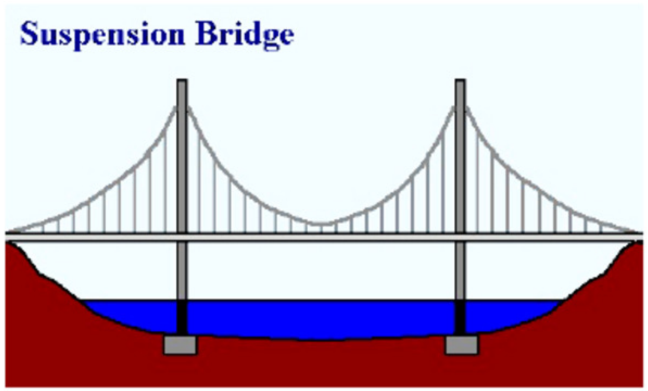
Part 1 Compression & Tension in Bridges

Read the following definitions and circle the correct word in each.

(1) If a member inside a bridge is 'in tension', we call it a *Tie* / *Strut*.

(2) If a member inside a bridge is 'in compression', we call ia a *Tie* / *Strut*.

Part 2 In the diagram of the bridge below, label the parts you think are in tension and the parts you think are in compression. You can use arrows to make it clear.

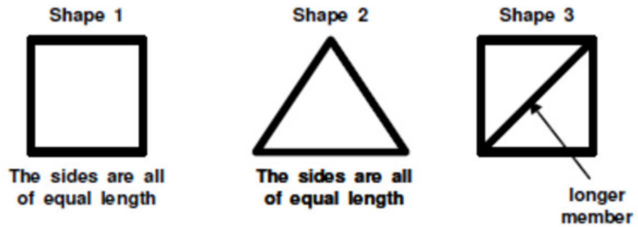


S2 - Bridges *Name:* ______________________

Part 1 Triangulation

In the kit provided, you should have five members. Four of them should be the same length and one should be longer. You should also have paper fasteners which fit through the holes on each end and allow you to connect members together.

Using this kit, build the following shapes and try moving them to find out if they are rigid or not.



Part 2 Think about what you have just found out and complete the following sentences.

(1) In order to be rigid, a shape ______________________________

____

(2) If a frame has no triangulation it ___________________________

____

(3) Describe, in your own words, why it is important to use triangulation when designing bridges:

____

____

____

Appendix 2
Pupil Task Sheet 5

S2 - Bridges *Name:* ______________________

Part 1

Cantilevers

(1) In your own words, describe what a cantilever is: ____________

____

____

(2) In your own words, describe what a cantilever bridge is: ______

____

____

Part 2

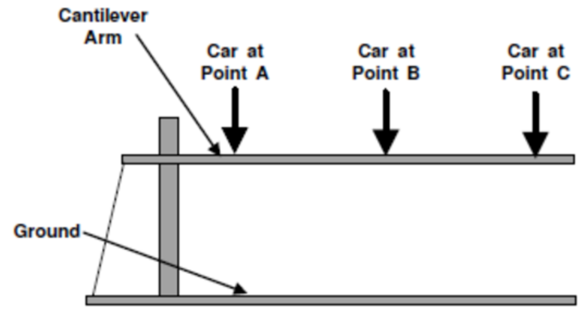
(1) In your own words, describe what a turning moment is: ______

____

____

(2) The diagram below shows a cantilever arm. There are three arrows labelled A,B and C that show the position of a car as it travel across the cantilever.

Draw your own arrows under point A, B and C to show how big the turning moment is. Use a long arrow to show a big turning moment, and a short arrow to show a small turning moment.



Appendix 3
Forms of Externalisation

Mental Process	**Predominant Manifestation**
Defining the problem or opportunity operationally	Symbolic, Non-Verbal & Verbal*
Observing	Non-Verbal
Analysing	Non-Verbal, Verbal, Symbolic
Visualising	Verbal, Symbolic
Computing	Symbolic, Verbal
Communicating	Verbal, Symbolic & Non-Verbal
Measuring	Non-Verbal, Symbolic
Predicting	Verbal
Questioning and Hypothesising	Verbal
Interpreting Data	Verbal, Non-Verbal, Symbolic
Constructing Models and Prototypes	Non-Verbal
Experimenting	Non-Verbal
Testing	Non-Verbal
Designing	Non-Verbal, Symbolic, Verbal*
Modelling	Non-Verbal
Creating	Verbal, Symbolic, Non-Verbal*
Managing	Verbal, Non-Verbal & Symbolic

Knowledge Category	**Predominant Manifestation**
Personal/Social	Verbal
Conceptual	Verbal, Non-Verbal, Symbolic
Procedural	Non-verbal, Verbal, Symbolic
Knowledge of Principles	Verbal
Contextual Knowledge	Verbal, Symbolic, Non-Verbal

Appendix 4
Pilot Study 1: Trial of Structured Observation Instrument using a Single Subject

1. Introduction

It is the intention of this pilot study to evaluate the structured observational instrument developed within the first section of the methodology for use within the main experiment. The instrument is designed to record the processes employed during technological problem solving. The internal mechanism of this instrument has been developed from the Flander's System of Interaction Analysis (Amidon & Powell, 1966).

2. Aims of Study & Evaluation Criteria

This study intends to evaluate the proposed instrument through the structured observation of one subject during technological problem solving. Whilst observational categories have been defined for the main study through the conceptual framework, the primary focus of this study is the mechanics of data gathering using this tool. It will be evaluated as a process against the following criteria, which should allow the logistics to be discussed as well as initial comments of validity.

Evaluation Criteria:

1. Overall ease of use of the instrument
2. Extent to which the instrument allows successful recording of identified processes in terms of:
   (a) Observational Timings
   (b) Format of Data Recording
3. Situational factors associated with the use of the instrument

3. Explanation of Evaluation Criteria

3.1 Overall Ease of Use of the Instrument

This relates to the use of the instrument from the researchers point of view and forms part of the emic considerations of the data-gathering instrument (see Borg & Gall, 2003, p438-439).

3.2 Observational Timings

Observational timings will be evaluated here against three criteria: Synchronicity, Practicality and Accuracy.

Criteria 1: Synchronicity

Within this study, the term 'synchronicity' is used to describe the extent to which the 'pace' of the observed phenomena matches the 'pace' of the observational instrument. While the pace of the observational instrument can be altered by varying the sampling intervals between observations, the pace of the observed phenomena in the context of technological problem solving is dependant upon a myriad highly complex and situational factors.

Figures 1 and 2 below illustrate the concept of 'synchronicity' for two different types of phenomena. These phenomena, which, under the context of this study would be tasks, have different properties and, as such, are represented by a circle and a square respectively.

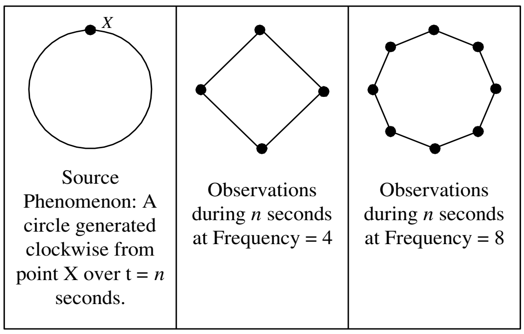


Figure 1 – Continuously Changing Activity

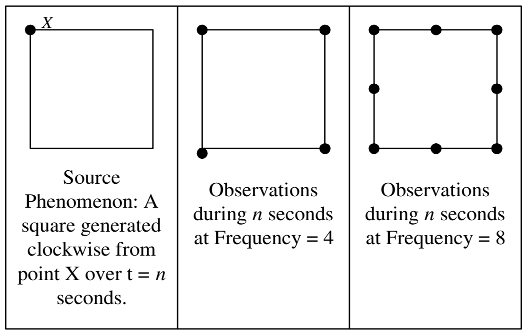


Figure 2 – Discontinuously Changing Activity

Figure 1 represents one end of the spectrum, where the phenomena or behaviours being observed are constantly changing over time. It is shown that as more observations of that phenomenon are made in *n* seconds, the more accurately the resulting data represents the original phenomena.

In Figure 2, the phenomenon is not constantly changing over time and it is shown that, in this case, four observations in *n* seconds are enough for the data to properly represent the phenomena. Whilst eight observations produce the same result, 50% of the observations are not required because the observational intervals are not synchronised with the phenomena. It is also conceivable that there will be periods observed where behaviours are continuously changing and periods where they are not.

Criteria 2: Practicality

Here, the term ‘Practicality’ is used to describe the ability of the researcher to firstly observe the phenomena, make a judgement against the defined observational categories and record this judgement to paper in the form of a corresponding code. The practicality is therefore affected by both the pace of the phenomena under investigation and the researchers ability to observe, judge and record events in the time intervals dictated by the observational instrument. This is one factor that could affect the validity of the data the instrument records.

Criteria 3: Accuracy

Within this study, the term ‘Accuracy’ refers to the overall level of detail with which that the observational instrument records the identified behaviours of the subject throughout the task as whole.

This measure can be conceived of as combinational effect of synchronicity and practicality; if the instrument is deemed to have good synchronicity and practicality, then it will also have accuracy for a given phenomenon and a sufficient level of validity. In summery, a good observational instrument:

- Will be well synchronised with the phenomena under investigation
- May be demanding but must be workable when used by a researcher
- Will be sufficiently accurate so as not to misrepresent the phenomena under investigation and lower overall validity.

3.3 Format of Data Recording

This will be examined in terms of the observational codes used during the observational period and how the data is recorded on the paper.

3.4 Situation Factors

This sections is concerned with the how the use of the instrument affected the environment in which it was used. Consideration will be given to the researchers role during the task and any points at which there was an observable effect on the subject.

4. Context for Study

The study took place within a small craft class that consisted of four boys aged between 12 and 14 years who were working independently. All four children had undergone the necessary learning in previous lessons and were now involved in the design and construction of a wooden artefact that constitutes any form of transport. The brief was given verbally by the teacher and was simply to construct something, using the available resources within the workshop environment, which would transport someone from one location to another. The children were free to progress through the project at more or less their own pace and the teacher was acting very much as a facilitator throughout this process. The duration of the lesson was 1 hour.

5. Procedures

An introductory session took place where time was spent discussing the intended with the children such that they understood what the aims were and that they could opt out at any point. The data-gathering instrument was then tested through a three-stage methodology. The first stage was an unstructured observation, the second stage was the identification of observational categories, and the final stage was a structured observation using these categories.

One boy, of twelve years old, was selected at random from the group and his actions and behaviour would henceforth be observed for the duration of the study. He had chosen to construct a car and had already spent time considering his design. He had produced three sheets of ideas, notes and sketches from which he was now working. He had completed construction of the body of the vehicle and had attached one of the front wheels.

After a brief analysis of the stage his solution was at, the list shown in Table 1 was produced outlining the predicted processes required for completion of the model car. It should be noted that this list is not intended to prescribe an order and that there are various orders in which the processes may be executed.

Predicted Processes	Description
Attach 2nd wheel	Attach 2nd Wheel to car using nail/screw
Drill 3rd wheel	Drill centre hole for 3rd wheel
Drill 4th wheel	Drill centre hole for 4th wheel
Attach 3rd wheel	Attach 3rd Wheel to car using nail/screw
Attach 4th wheel	Attach 4th Wheel to car using nail/screw
Sand artefact	Sand artefact ready to receive finish
Finish artefact	Paint, Stain, Varnish, Oil artefact to provide aesthetic and protective coating

Table 1 – Predicted Processes for Task Completion

6. Data Gathering Stages

The following section describes each of the three stages in the gathering data.

Stage 1: Unstructured Observation (15 minutes, Start of Lesson)

This observational period was used to further identify the processes and strategies that were being employed by the subject in the context of this task. This was done to both validate and, if required, supplement the list of predicted processes. Observations of these events and strategies were noted down successively throughout the lesson.

Stage 2: Development of Observational Categories

The results from the unstructured observation were examined in conjunction with the predicted processes and a list of eleven separate identifiable actions and processes were defined. This processes of prediction; validation and supplementation ensured that the behaviours that form the content of the observational instrument would almost definitely be manifest within this given task. The resulting behaviours, used to form the observational categories, are thus highly context specific and are not intended for generalisation. The observational categories were manually filled in to the observation schedule before the structured observation. The schedule used is shown in Figure 3.

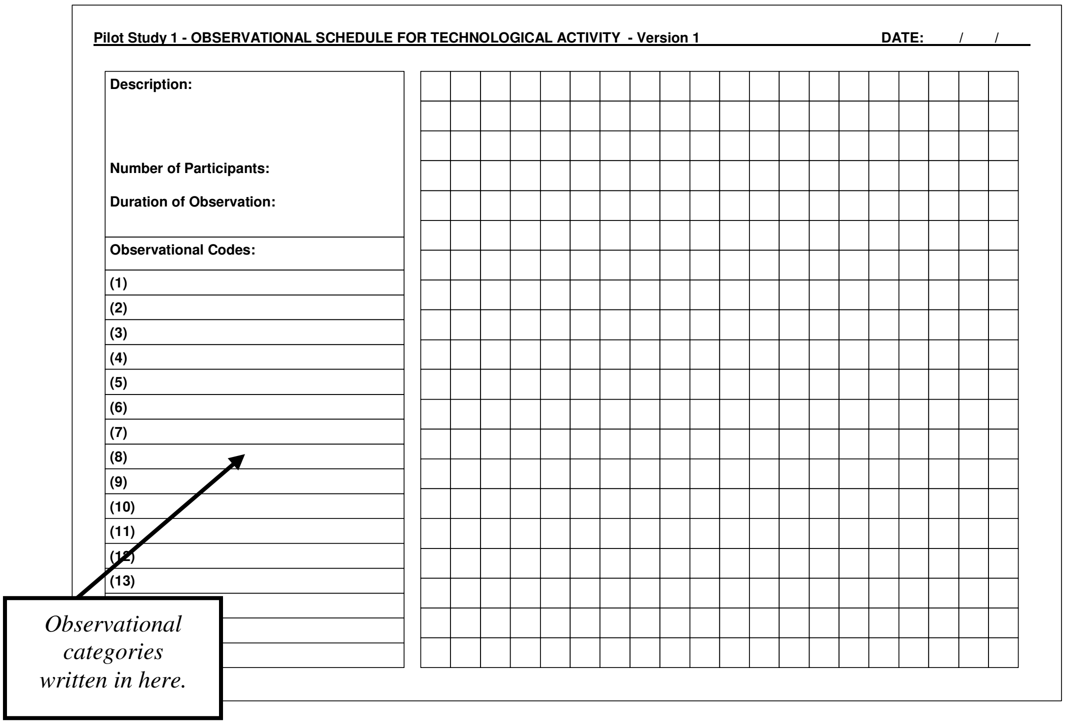


Figure 3 – Observational Schedule

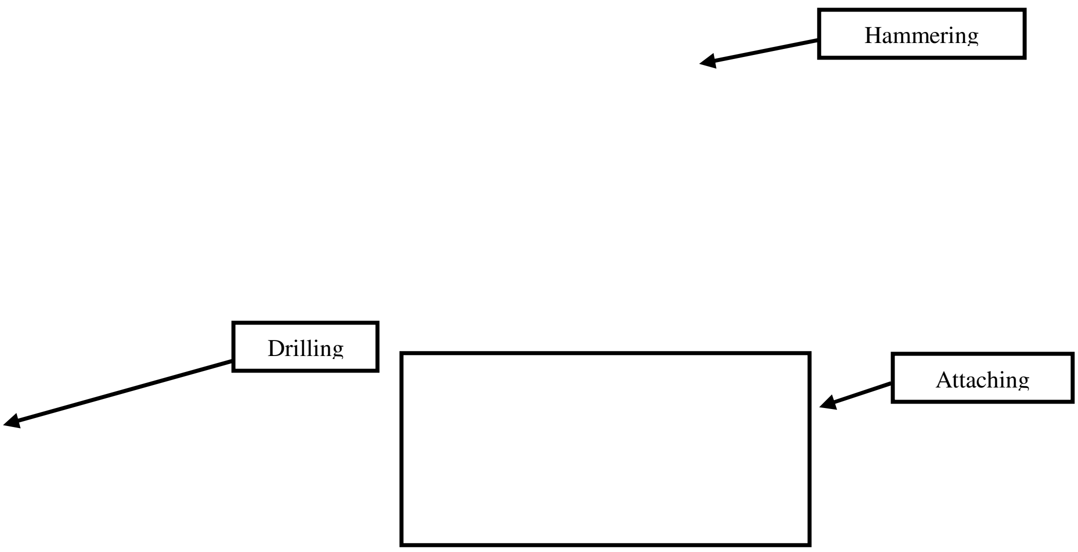
Stage 3: Structured Observation (20 minutes)

This structured observation was carried out using the framework developed in the Flander's System of Interaction Analysis. Using the eleven identified observational categories, the processes and actions of the subject were recorded every three seconds.

7. Results

7.1 Results of Unstructured Observation

The notes generated throughout the unstructured observation were quite extensive. Some portions of these observations have been transcribed below. The extracts have been selected to show the identification of selected observational categories. Extract A sees the subject drilling one of the required holes into the centre of the wooden wheels and, in extract B, the subject is attempting to attach a wheel to the body of the vehicle.



Example Extract A	Example Extract B
"tightens clamp on w/p"	"hammer nail into w/p"
"lowers drill"	"w/p moves"
"checks drill against centre w/p"	"re-evaluates"
"loosens clamp"	"examines w/p"
"adjusts position w/p"	"nail not centred"
"lowers drill"	"lifts w/p"
"checks position"	"holds hammer near top"
"tightens w/p"	"puts w/p on bench"
"turns drill on"	"puts nail through hole"
"lowers drill"	"holds wheel and w/p"
"drills hole"	"hammers nail"
"re-passes drill"	"hit thumb"
"switch drill off"	"re-adjusts grip position hammer"
"loosens w/p"	"hammers nail"
"examines hole"	"Tests if wheel turns"

Table 2 – Extracts from Notes Taken During Unstructured Observation

7.2 Development of Observational Categories

Through an examination of the observations made during the first section and consideration of the given task, the actions and processes shown in Table 3 were identified for use within the structured observation. This list is not intended to be inclusive of all identifiable processes.

Observational Category	Description
Hammering (1)	Use of hammer and nail by subject
Testing (2)	Subject tests an aspect or part of the developing artefact
Questioning (3)	Subject asks question of teacher
Responding (4)	Subject responds verbally to teacher
Listening (5)	Subjects listens to teacher
Attaching (6)	Subject attaches two components together
Painting (7)	Subject paints artefact
Marking (8)	Subject marks artefact to aid construction in some way
Clamping (9)	Subject clamps piece before or after drilling or cutting
Sanding (10)	Subject sands artefact or component of artefact
Drilling (11)	Use of pillar drill by subject
Idle (12)	Subject off-task or waiting

Table 3 – Identified Observational Categories

7.3 Results of Structured Observation

Below, Table 4 illustrates the observations made over a twenty-minute period using three-second intervals. The table reads from left to right.

Min	Time Intervals (seconds)																			
	0	***3***	***6***	***9***	***12***	***15***	***18***	***21***	***24***	***27***	***30***	***33***	***36***	***39***	***42***	***45***	***48***	***51***	***54***	***57***
0	5	5	5	5	4	12	12	12	1,6	1,6	2	2	1,6	1,6	1,6	1,6	2	1,6	1,6	2
1	2	1,6	1,6	2	1,6	1,6	2	5	5	5	4	4	5	1,6	1,6	1,6	2	5	4	1,6
2	2	12	12	2	2	1	1	1	2	2	1	1	1,6	1,6	1,6	2	2	12	12	3
3	3	3	5	4	3	5	5	5	4	12	12	2	1,6	1,6	1,6	1,6	2	2	4	4
4	12	1	1	1	1,6	1,6	1,6	1,6	2	2	2	2	1	1	2	2	1	1	1,6	1,6
5	1	2	2	2	1	1,6	2	3	3	8	8	8	8	8	8	12	12	2	2	2*
6	9	9	9	9	9	2	2	11	11	11	11	11	11	9	9	12	12	2	12	12
7	12	12	10	10	10	10	10	10	10	12	1,6	1,6	1,6	1,6	1,6	2	1,6	2	2	1,6
8	1,6	1,6	6	6	1,6	2	2	1,6	1,6	1,6	2	12	12	5	4	2	12	12	1,6	1,6
9	1,6	2	1,6	1,6	1,6	2	2	1,6	2	2	1,6	1,6	1,6	1,6	2	2	1,6	1,6	6	6
10	1,6	1,6	2	2	1,6	1,6	1,6	2	2	12	2	2*	1,6	1,6	1,6	1,6	1,6	2	2	1,6
11	1,6	2	2	12	12	12	3	3	5	5	5	4	12	12	12	12	10	10	10	10
12	2	10	10	10	10	10	10	10	10	10	10	2	2	10	10	10	10	2	10	10
13	10	10	10	10	10	2	10	10	10	2	10	2	10	10	10	10	2	10	10	10
14	10	10	10	10	10	10	10	10	2	10	10	10	10	10	2	10	10	10	2	10
15	2	10	10	10	2	10	10	2	10	10	10	12	12	12	3	3	5	12	5	5
16	5	4	12	12	10	10	10	10	2	10	10	2	10	10	10	2	10	10	10	10
17	10	10	10	2	12	12	3	12	5	4	3	3	5	3	5	5	5	4	12	12
18	12	12	12	12	12	12	7	7	7	7	7	7	7	7	7	7	7	7	7	7
19	7	7	7	7	7	7	7	7	7	7	7	7	7	7	5	4	7	7	7	7

(indicates observation of situational factor)*

Table 4 – Results of Structured Observation

8. Analysis & Discussion

8.1 Overall Ease of Use of Instrument

The data-gathering instrument was definitely more difficult to use within the first minute or so. During this time, there would arguably be concerns over validity. However, after this period, the balance of concentration required between the observational schedule and the subject under observation was refined. Moreover, the ease of use was increased further during this time as the researcher became more aware of pace and of the observational foci the instrument was designed to record.

8.2 Observational Timings - Synchronicity

Whilst it was recognised, during the observation, that the pace with which the subject progressed towards a complete solution was not as great as had been thought, there were several instances indicated in the results where behaviours were observed changing within a three second period. Some of these are shown below in Tables 5, 6 and 7.

Min	Time Intervals (seconds)																			
	0	***3***	***6***	***9***	***12***	***15***	***18***	***21***	***24***	***27***	***30***	***33***	***36***	***39***	***42***	***45***	***48***	***51***	***54***	***57***
1	2	1,6	1,6	2	1,6	1,6	2	5	5	5	4	4	5	1,6	1,6	1,6	**2**	**5**	**4**	**1,6**

Table 5 - Example 1: (1 min. 48s > 1 min. 57s)

Min	Time Intervals (seconds)																			
	0	***3***	***6***	***9***	***12***	***15***	***18***	***21***	***24***	***27***	***30***	***33***	***36***	***39***	***42***	***45***	***48***	***51***	***54***	***57***
3	3	3	**5**	**4**	**3**	**5**	5	5	4	12	12	2	1,6	1,6	1,6	1,6	2	2	4	4

Table 6 - Example 2: (3 min. 6s > 3 min. 15s)

Min	Time Intervals (seconds)																			
	0	***3***	***6***	***9***	***12***	***15***	***18***	***21***	***24***	***27***	***30***	***33***	***36***	***39***	***42***	***45***	***48***	***51***	***54***	***57***
15	2	10	10	10	2	10	10	2	10	10	10	12	12	12	3	**3**	**5**	**12**	**5**	5

Table 7 - Example 3: (15 min. 45s > 15 min. 54s)

While the results indicate that there were periods where the same process was carried out for long durations, three-second intervals provided a suitable duration to record even the more rapidly changing periods of activity. The histogram shown in Figure 5 was generated to indicate the number of occurrences where codes were recorded successively over a given number of 3-second intervals. Groups of codes were coloured and counted. The first two row of data having undergone this process are shown in Figure 4:

2	1,6	1,6	2	1,6	1,6	2	5	5	5	4	4	5	1,6	1,6	1,6	2	5	4	1,6
2	12	12	2	2	1	1	1	2	2	1	1	1,6	1,6	1,6	2	2	12	12	3

Figure 4 – Coding of Data Groups for Histogram

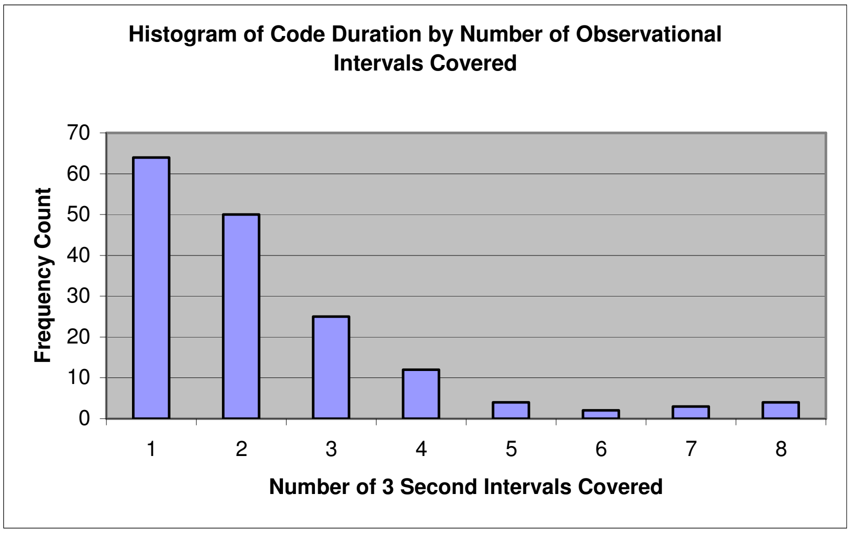


Figure 5 – Histogram of Code Durations

The histogram illustrates a unimodal positive skew and a significantly larger number of instances where behaviours lasted only one three-second interval. This declines almost exponentially as the number of three-second intervals covered increases.

This strongly suggests that the synchronicity between the phenomena and observational instrument was sufficient.

8.3 Observational Timings - Practicality

Although the use of the instrument was more difficult to begin with, it was possible to make an observation, judgement and code this to paper within the three-second interval. The most difficult and time-consuming aspect of this process was ensuring that the correct code was being used for the observed behaviour. From this, it was clear that the more familiar the observational codes became, the less demanding the coding task became.

8.4 Observational Timings - Accuracy

Generally, there were not many instances where the pace of the events being observed was too fast to record and only a handful of instances where difficulty was found in the practical use of the instrument. From this it can be argued that the overall sensitivity of the instrument was fairly good. However, as indicated in Table 8, there were instances where the subject was recorded performing more than one behaviour or process at the same time:

Min	**Time Intervals (seconds)**																			
	0	***3***	***6***	***9***	***12***	***15***	***18***	***21***	***24***	***27***	***30***	***33***	***36***	***39***	***42***	***45***	***48***	***51***	***54***	***57***
0	5	5	5	5	4	12	12	12	**1,6**	**1,6**	2	2	**1,6**	**1,6**	**1,6**	**1,6**	2	**1,6**	**1,6**	2

Table 8 – Instances of Simultaneous Coding of Two Behaviours

In this instance, it is by virtue of the fact that some observational categories, by definition, subsume others. The act of hammering necessitates that the subject is also attaching. In a sense, the subject is therefore really only still carrying out one observable processes that can be described in two ways. 17% of the codes entered accounted for two observational categories in this manner. Only one combination of the two codes was recorded.

Additionally, it is also conceivable that here will be times when the subject is performing two or more separate processes that are not subsumed, but the categories and the nature of the activity did not result in this during the study.

This possibility was not previously accounted for and can be seen to add the dimension of 'depth' to the observational instrument. To a large extent, this can be accounted for by the change in context between that used by Flander's and that used within this study. The context within the Flander's System supports an ostensibly reciprocal verbal relationship between two entities: class and teacher; whilst here, the context supports a relationship between pupil and task which has been shown may operate on more than one level at any given point in time. This again could add to the demand placed on the researcher but suitable practice and familiarity with what is under examination would alleviate this.

8.5 Format of Data Recording

The recordings of data as a numerical code throughout the study worked quite well, however, there were instances where there was difficulty in locating the number of a given code. This was partly due to their positioning and partly because they were hand written very quickly. In this study, this represents a threat to validity and should be revised for the second study.

The raw data was recorded in a grid from left to right. While this initially seemed to work quite well, it did not allow for any other data to be recorded and space for codes sometimes appeared limited. This became an issue when trying to record any situational factors that were observed.

8.6 Situational Factors

As evidenced in the results, there were only two instances throughout the structured observation where a direct situational factor was recorded. In both of these instances, the subject's attention moved from the task in hand to the researcher. This was indicated through line of sight. These instances were momentary and did not appear to affect the subject's activity, however, all possible measures should be taken to minimise these and their occurrences should be noted. It is also recognised that there were most likely additional affects that were not obvious to the researcher and this will be addressed in the main study through discussion with the class teacher.

9. Recommendations

As a result of the results and discussion of the above study, the following recommendations can be made and applied to subsequent studies.

(1) The time interval for making observations should remain three seconds.
(2) The observational instrument should be augmented to allow for more than one process to be recorded at the one time should this take place.
(3) Very clear definitions of the behaviours that constitute each observational category must be developed.

(4) The observational categories and subsequent codes should be ordered according to those predicted for the given task. Where possible, this would mean that the processes most likely to happen first are listed first and so forth.

(5) The observational instrument should be augmented so that account can be taken of any situational factors that occur during the task.

Appendix 5
Pilot Study 2: Trial of Structured Observation Instrument using a Two Subjects

1. Introduction

This forms the second pilot study carried out to evaluate the effectiveness and use of the developed observational instrument. Whilst the first pilot study evaluated the use of the tool observing an individual child, this study will apply it to observe a paired technological task. The subject of the task will be kept the same and hence, the predicted processes that could be observed are expected to be largely similar.

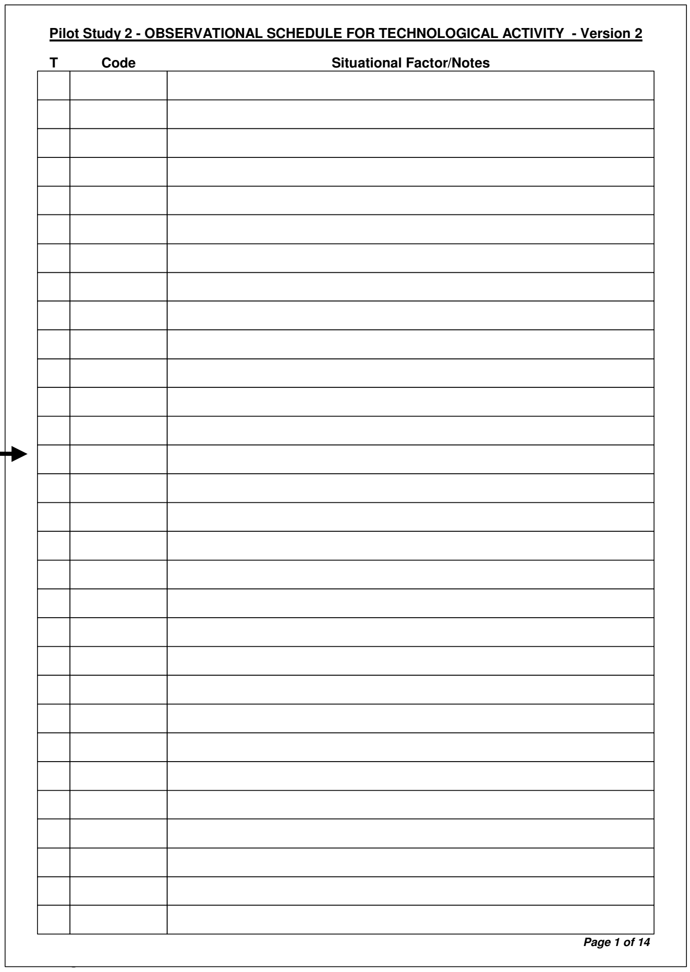
2. Refinements Arising From The Recommendations of Pilot Study 1

(1) The observational time interval will remain 3 seconds

(2) Instead of recording associated codes in a simple grid, they will be recorded in a linear-sequential observational schedule. The updated schedule developed for this pilot study is shown below. Figure 1 shows the schedule itself and Figure 2 shown the observational categories grid.

This is fixed to a custom made clip board that allows the pages to be easily turned.

It is situated below the observational categories grid, which remains fixed throughout.


Pilot Study 2 - OBSERVATIONAL SCHEDULE FOR TECHNOLOGICAL ACTIVITY - Version 2

T	Code	Situational Factor/Notes

Page 1 of 14

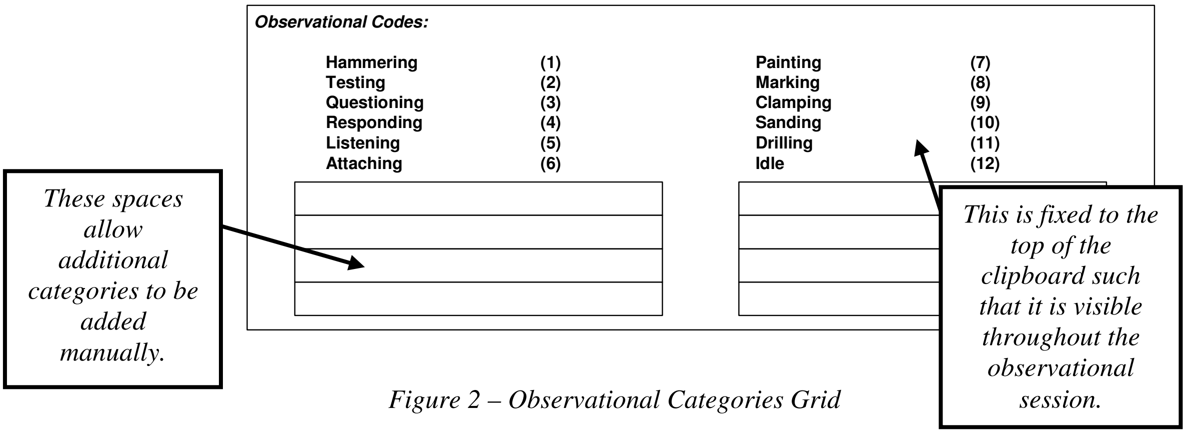


Figure 2 – Observational Categories Grid

The following amendments were made in developing the revised schedule:

- The schedule is completed from the top downward instead of left to right
- Multiple columns have been introduced to allow the recording of additional observable factors
- The schedule is spread over multiple pages allowing more space for codes to be recorded

One further recommendation from the first study was that the observational categories be ordered in accordance with the order most likely to be observed. It was felt that this would be logistically very difficult in the time frame for this study and will be considered in the following study where the observational categories are known beforehand.

3. Aims of Study & Evaluation Criteria

The refined observational schedule will be applied to observe a pair of pupils undertaking a technological problem-solving task jointly. More specifically, an evaluation will be carried out against the following criteria:

1. Overall ease of use of the instrument with the refined observational schedule
2. The extent to which the refined instrument allows successful recording of identified processes in terms of:
   (a) Observational Timings
   (b) The Format of Data Recording.
3. Identification of any increased demands engendered by observing a higher number of participants

4. Explanation of Evaluation Criteria

The following section describes each of these criteria in more detail.

4.1 Ease of Use of Revised Schedule

This refers to the use of the paper-based schedule with the aforementioned amendments. Here, consideration will also be given to the increased familiarity with the observational codes prior to the observations taking place.

4.2 Observational Timings

This will again be considered using the same criteria as defined within pilot study 1:

Criteria 1: Synchronicity

How the pace of the observed activity compares to the pace of the observational instrument.

Criteria 2: Practicality

The ability of the researcher to observe, judge and record behaviours during the problem solving session.

Criteria 3: Accuracy

Level of detail and overall representation of the phenomena that took place.

4.3 Format of Data Recording

This will explore the codes employed and how they are used with the revised observational schedule.

4.4 Identification of Increased Demand on Researcher

In many ways, this can be considered a culmination of relevant aspects of the above criteria from the perspective of the researcher. The critical consideration here will be whether or not increasing the number of pupils being observed places an additional demand on the researcher.

5. Context for Study

This study took place within a similar small craft class to the first study. This class consisted of six boys aged between 9 and 13 years of age. The boys had arranged themselves into pairs and, as with the previous study, had undergone the necessary learning associated with the task they were undertaking. The theme selected was transport and the children again had to manufacture the artefact in wood. The teacher again delivered the brief verbally and they had access to all necessary resources in the workshop. Once more, the children were free to progress through the project at their own pace and they had more than sufficient time to complete it. The teacher facilitated the process and supported the boys where necessary and whilst the project ran over several periods, the observation for this pilot study took place over a single 1-hour lesson.

6. Procedures

As with the previous pilot study, the research intentions were discussed with the boys who had the opportunity to opt out. They all agreed to take part in the observation. The three pairs were allocated a number by the teacher known only to him and one was selected randomly for observation. The group in question consisted of one boy aged 10 and one boy aged 11 years. During this study, a similar three-stage methodology was followed. Firstly, the predicted processes were considered through an unstructured observational period. This allowed a judgement to be made as to the suitability of the observational categories established in the first pilot study. Any amendments to the observational categories would constitute a second stage. The third stage involved applying the revised schedule with amended categories in a structured observation of the boys' activity.

As with the first study, the participants have already undergone the initial phase of the task during which a page with some initial sketches and ideas was produced. The dyad in question had chosen to create a Plane as their mode of transport, however, had not begun any physical construction at this point.

7. Data Gathering Stages

The following section describes each of the data gathering stages in more detail.

Stage 1: Unstructured Observation (15 Minutes)

Here, the unstructured observation was used to ascertain the initial intentions of the pair with regard to the possible processes they would undertake. Additionally, this could be used to confirm or amend the observational categories developed in the initial pilot study. During this stage, notes were made freely on a pad to describe the behaviours being observed.

Stage 2: Amendment of Observational Categories

Because of the similarity to the activity observed in the first pilot study, there was no intention here to remove any of the observational categories but additional ones could be added. It is again hoped that this process will confirm the likelihood of behaviours occurring during the observational period. The intention is not to make any assertion of reliability or generalisation to any other similar circumstances at other locations or points in time, but simply give some indication that they are likely to occur during the remainder of this observation session. This is sufficient to further test the data-gathering tool.

Stage 3: Structured Observation (20 Minutes)

This stage was used to apply the amended observational schedule to the activity of the pair of boys. Here, it is important to note that the rationale for observation is still in accordance with Flander's System of Interaction Analysis. The events that prompt judgements to be made regarding categorisation and coding are based upon the interaction between the pupils and the developing solution. No attempt was made to distinguish between individual pupils. Additionally, this observation was carried out with an electronic timer located at the top of the clipboard.

8. Results

8.1 Results of Unstructured Observation

As with the first pilot study, the notes generated over this period were fairly detailed. The extract in Table 1 has been selected to show the identification of selected observational categories. Here, both boys are marking out the shape of the body of the plane on one side of the timber (as shown in Figure 3).

Example Extract
Places timber on paper below sketch
Boys look and one takes pencil
Starts marking front of the plane freehand
Is stopped by other says should measure
Boys discuss, decide sketch is not good enough but should use as guide
Suggest start at back is easier
States should start with slope at back
Takes ruler and measures width at back of timber
Makes half way mark with pencil
Lines edge of rule with mark, positions diagonally toward bottom of plane
Other boy moves rule slightly whilst other still

Discussion

Measuring

holds
States 'go' and boy draws a line, goes over it several times
Other takes pencil and darkens same line on sketch
Boys question/discuss where tail wing will be stuck
Estimate position and shade it on side of timber

Marking/Writing

Table 1 – Extract of Results From Unstructured Observation

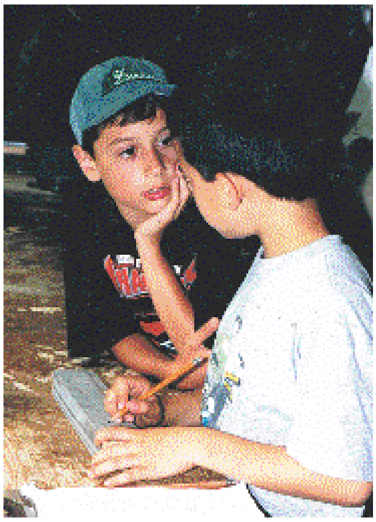


Figure 3 – The Two Boys Beginning to Mark the Body of the Plane

8.2 Re-Consideration of Observational Categories

This was done through both an examination of the notes taken during the first observational stage and consideration of the next stage the boys would have to undertake. The section they had to deal with before the end of the period involved marking and cutting the joint that would allow them to attach the wings of the plane to the body.

It should be noted that although marking and writing were identified as a process in the analysis, the previous study had also identified marking as process whereby the subject marks lines or points on the artefact. Subsequently, the additional process will be termed 'writing/recording' to account for the instances where subjects marked information on paper.

The additional observational categories established are shown in Tables 2 and 3. Table 4 shows all observational categories used in the structured observation.

Observational Category	**Description**
Discussing (13)	Discussion between the subjects in the dyad about the task at hand.

Measuring (19)	Determining distances using a steel rule or other device.
Writing/Recording (17)	Recording of information, written or diagrammatic, on paper.
Holding/Showing (16)	Holding of material or object by a subject to facilitate another process/holding or manipulating object to aid in describing and idea.

Table 2 – Categories Established through Analysis of Notes

Observational Category	**Description**
Chiselling (14)	Removal of sections of timber using a Bevel-Edged or Firmer Chisel.
Sawing (15)	Cutting of timber using a Tenon Saw.

Table 3 – Categories Established by Consideration of Likely Next Steps

Observational Category	**Description**
Hammering (1)	Use of hammer and nail by subject(s)
Testing (2)	Subject(s) tests an aspect or part of the developing artefact
Questioning (3)	Subject(s) asks question of teacher
Responding (4)	Subject(s) responds verbally to teacher
Listening (5)	Subject(s) listens to teacher
Attaching (6)	Subject(s) attaches two components/parts together
Painting (7)	Subject(s) paints artefact
Marking (8)	Subject(s) mark artefact to aid construction in some way.
Clamping (9)	Subject(s) clamps work-piece before drilling or cutting.
Sanding (10)	Subject(s) sands artefact or component of artefact.
Drilling (11)	Use of pillar drill by subject(s).
Idle(12)	Both subjects off-task or waiting.
Discussing (13)	Discussion between the subjects in the dyad about the task at hand.
Chiselling (14)	Removal of sections of timber by subject(s) using a Bevel-Edged or Firmer Chisel.
Sawing (15)	Subject(s) cutting timber using a Tenon Saw.
Holding/Showing (16)	Subject(s) holding of material or object by a subject to facilitate another process/holding or manipulating object to aid in describing and idea.
Writing/Recording (17)	Subject(s) recording of information, written or diagrammatic, on paper.
Measuring (19)	Subject(s) determining distances using a steel rule or other device.

Table 4 – All Observational Categories Employed During Structured Observation

8.3 Results of Structured Observation

Tables 5 and 6 show the results of the structured observation over a sixteen-minute and 54 second period. There was insufficient time to observe for the intended twenty-minute duration.

9. Analysis & Discussion

9.1 Overall Ease of Use of Instrument

There was a notable difference undertaking this observation. A firmer knowledge of most of the observational categories definitely helped and there was a feeling of increased confidence with the validity of observation in the first two minutes. It should still be noted, however, that it still takes a certain amount of time to regulate the pace of observations and there was a higher frequency of observations where two codes were recoded. It was, however, easier to regulate the pace than with the first study.

The fact that there were two subjects involved in this observation did not significantly increase the demand on the researcher. After consideration, it was thought that there were two principle reasons for this.

Firstly, despite there being two boys in this group, the nature of their approach towards the task meant that, for a large proportion of the time, the direct interaction with the artefact was undertaken by only one of them. They did alternate from time to time, however, most of the instances where they were acting collaboratively involved discussion and demonstration of ideas to one to the other. These were accounted for by only two codes resulting in no significant increase in demand. There were more instances where two codes were entered and this did require additional judgements but was still feasible in the 3-second duration. It is likely that it would have been significantly more demanding if they decided to work on separate parts of the developing solution simultaneously.

T	***Codes***	***Notes***	***T***	***Codes***	***Notes***	***T***	***Codes***	***Notes***	***T***	***Codes***	***Notes***
0	16, 13		0	13	3min	0	12	6min	0	13, 16	9min
3	16, 13		3	13		3	19		3	13	
6	16		6	13		6	19		6	13, 16	
9	16		9	13		9	13		9	13, 16	
12	16, 13		12	13		12	13, 17		12	12	
15	16, 13		15	12		15	13, 17		15	12	
18	16, 13		18	12		18	16		18	13	
21	16		21	13		21	16		21		
24	16, 13		24	13		24	16, 13		24	Reading sizes from paper	
27	13		27	13		27	16, 13		27		
30	13		30	13		30	16		30		
33	13		33	12		33	16, 8		33	16	
36	12		36	12		36	16, 8		36	16	
39	12	*	39	12		39	8		39	13, 16	
42	16, 13		42	12		42	12		42	13, 16	
45	13, 8		45	12		45	12		45	16	
48	13, 8		48	12		48	8, 13		48	13, 16, 8	
51	8		51	12		51	8, 13		51	13, 16, 8	
54	8		54	5		54	13		54	16, 8	
57	8		57	5		57	12		57	16	
0	12	1min	0	5	4min	0	8, 12	7min	0	16	10min
3	12		3	5		3	8, 12		3	12	
6	13		6	16, 4		6	8		6	12	
9	13		9	16, 4		9	8		9	12	
12	13		12	16		12	16, 8		12	12	
15	13		15	16, 5		15	16, 8		15	12	
18	8		18	16, 4		18	12		18	12	
21	19, 16		21	5		21	8		21	12	
24	19, 16		24	5		24	8		24	12	
27	19, 13		27	16, 4		27	12		27	12	
30	19, 13		30	16, 4		30	8, 13		30	12	
33	13		33	12		33	8		33	12	
36	13, 17		36	3, 16		36	8, 13		36	16, 19	
39	17		39	3, 16		39	8		39	16, 19	
42	13		42	5		42	8		42	16	
45	13, 2, 16		45	5		45	12		45	16, 8	
48	13, 2, 16		48	3		48	12		48	16, 8	
51	2, 16		51	3		51	8, 13		51	16	
54	2, 16		54	5		54	13		54	13	
57	13, 2, 16		57	5		57	12		57	13	
0	13, 16	2min	0	5	5min	0	12	8min	0	12	11min
3	13, 16		3	5		3	12		3	12	
6	16		6	5		6	12		6	12	
9	13, 16		9	4		9	13		9	13	
12	13, 16		12	4, 16		12	13		12	3	
15	13, 16		15	5		15	13		15	3	
18	12		18	5		18	8, 13		18	12	
21	12		21	4, 16		21	8		21	12	
24	12		24	4, 16		24	12		24	12	
27	13		27	16		27	12		27	5	
30	13		30	5, 16		30	8, 13		30	5	
33	13		33	5		33	8, 13		33	5, 4	
36	13		36	5		36	12		36	5, 4	
39	12		39	13		39	13		39	5	
42	19		42	13		42	13		42	5	
45	19		45	16		45	12		45	4	
48	2		48	19, 16		48	13		48	5, 4	
51	2, 13		51	19, 16		51	12		51	16, 4	
54	13		54	16		54	12		54	16	
57	13		57	12		57	13, 16		57	16	

** indicates an observable situational factor*

Table 5 – Results of Structured Observation (0 – 11min, 59s)

T	*Codes*	*Notes*	*T*	*Codes*	*Notes*	*T*	*Codes*	*Notes*	*T*	*Codes*	*Notes*
0	9	12min	0	5	15min						
3	9		3	16, 13							
6	9		6	16, 13							
9	9, 13		9	13							
12	9, 13		12	13							
15	9		15	12							
18	9, 13		18	12							
21	9		21	12							
24	16, 13		24	14	*						
27	16, 13		27	14	*						
30	13, 15		30	14							
33	15		33	12							
36	15		36	14							
39	15		39	14							
42	15		42	14, 13							
45	15, 2		45	14, 13							
48	13, 2		48	14, 13							
51	13, 2		51	14							
54	9, 13		54	14							
57	9		57	14, 13							
0	9	13min	0	14, 13	16min						
3	13		3	14							
6	13		6	12							
9	15		9	12							
12	15		12	14							
15	15		15	14							
18	15, 2		18	14, 13							
21	15, 2		21	14, 13							
24	2		24	13							
27	13		27	13							
30	13		30	13							
33	12		33	5							
36	12		36	5							
39	12		39	5	*						
42	12		42	5, 4	*						
45	3		45	4							
48	12		48	4							
51	13		51	4, 13							
54	13		54	4, 13							
57	5		***End of Observation***								
0	5	14min									
3	5										
6	5										
9	4										
12	5										
15	5										
18	5										
21	5										
24	4										
27	3										
30	3										
33	5										
36	5										
39	5	*									
42	5	*									
45	13										
48	13										
51	5										
54	5										
57	5										

** indicates an observable situational factor*

Table 6 – Results of Structured Observation (12min – 16min, 54s)

Secondly, the fact that there were two participants forced a more refined way of thinking when making judgements. In practical terms, this meant that the emphasis of the observation was such that the primary object of focus was the developing artefact rather than the subjects themselves. Hence, the actions of the subjects were of greatest importance when they were seen to interact with the developing solution. This is will also be the intention in the main study, as the importance of verbalised interaction will be captured through recordings.

9.2 Observational Timings – Synchronicity

The pace of the subjects activity in this observation appeared slower than that within pilot study 1. Despite this, there were again several instances where behaviours were recorded as changing within 3-second durations. Examples of this are shown in Tables 7, 8 and 9.

	33	13	
	36	13, 17	
	39	17	
	42	13	
	45	13, 2, 16	

Table 7 - Example 1: (1 min. 33s > 1 min. 42s)

	21	4, 16	
	24	4, 16	
	27	16	
	30	5, 16	
	33	5	

Table 8 - Example 2: (5 min. 24s > 5 min. 33s)

	12	9, 13	
	15	9	
	18	9, 13	
	21	9	
	24	16, 13	
	27	16, 13	

Table 9 - Example 3: (5 min. 24s > 5 min. 33s)

These examples again suggest that there is merit in maintaining a sampling interval of 3 seconds. Further to this, a Histogram, shown in Figure 4, was developed from the data indicating the frequency of observational codes entered that span a given number of sampling intervals. These range from 1 interval to 8 or more intervals.

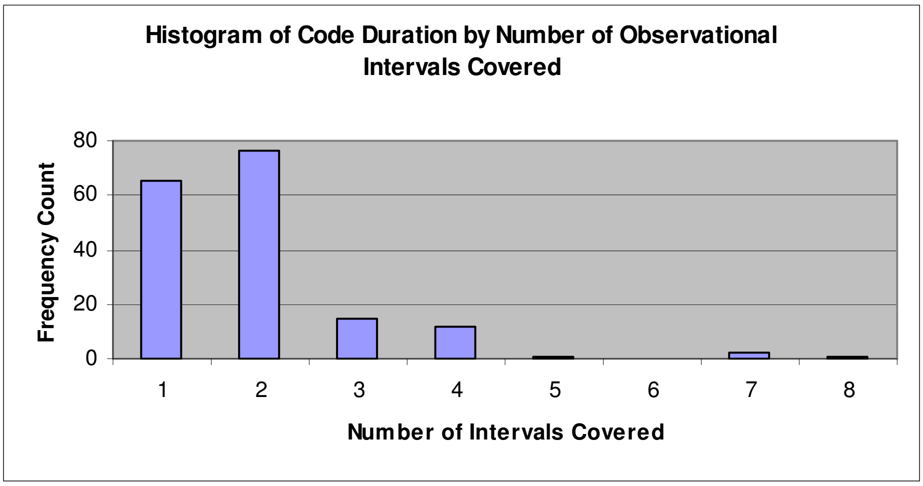


Figure 4 - Histogram of Code Durations

The results of this histogram would suggest that, in comparison to that of the first pilot study, the mode has shifted slightly with a greater frequency of behaviours lasting for two sampling intervals (between 3 and 6 seconds). The reasons as to why these changes have occurred could be many and varied and are out-with the scope of this discussion. Despite this, the graph exhibits the same broad characteristics in that it is unimodal with a positive skew, which further supports the notion of employing a sampling interval of 3 seconds.

9.3 Observational Timings – Practicality

Although it is now very clear that the act of observing and coding behaviour of this type using 3-second sampling intervals is demanding, it was notably eased with increased familiarity of those behaviours that belong to each code. The new behaviours that were added during this study were, with the possible exception of holding or showing, very specific, unambiguous and readily recognisable. The category for holding or showing was harder to judge as there were instances where the subject was holding the artefact for no functional reason within the context of the task. As such, this is not of interest to the study but identifying the point at which the holding of the artefact ceases to serve a purpose was challenging. An instance of this was noted on the observational schedule from around 9 mins. 39 seconds to 10 mins. 9 seconds as shown in Table 10, below:

39	13, 16
42	13, 16
45	16
48	13, 16, 8
51	13, 16, 8
54	16, 8
57	16
0	16
3	12
6	12
9	12
12	12

Table 10 – Example Instance of Three Behaviours Coded Simultaneously

As can be seen here, the subject is holding the artefact from 9m39s to 10m00s (code 16) and is then recorded as being off-task (code 12). At this point, the two boys entered into unrelated discussion but the artefact was still being held. It was not recorded as such because there was no function associated with the behaviour within the context of the task. It should also be noted that this was a decision made during the early stages of the coding process.

The importance of well-defined and well-understood observational categories again appears essential for the observation to be carried out successfully.

The introduction of the timer at the top of the clipboard was beneficial. This was mostly true for the initial few minutes where time is taken to find the correct pace. After this, it was referred to only fleetingly and, in most instances, confirmed that the observations were on schedule. The largest mismatch recalled between the timer and the timing of the observational coding was about 4 seconds. This accounts for just over one sampling interval but within the context of the duration of the observation and the number of samples taken is not seen as a major concern. It equally stands to reason that some samples will have been made slightly quicker and the overall error effect will cumulatively be lessened. The inclusion of complete timings in the final observational schedule would help should this become problematic.

One instance was observed where the behaviour of the subject was not represented in the observational categories. Between 9m21s and 9min30s, one of the subjects was reading previously written sizes from a page to the second subject. This was recorded in note form, as it will be in the main study should this situation arise.

9.4 Observational Timings – Accuracy

The depth of information recorded by the instrument was, in instances, greater than that recoded in the first pilot study. There were between one and three codes entered for each sample taken and their percentage representation for each study is given in Table 11, below.

	% of Single Codes Recorded	% of Double Codes Recorded	% of Triple Codes Recorded
Pilot Study 1	83%	17%	-
Pilot Study 2	64.3%	33.3%	2.4%

Table 11 – Percentage of Single and Multiple Code Recordings by Study

In the instances where three codes were noted, demand on the researcher was not as great because most of the codes recorded were subsumed by others. The example in Table 12, below, from 9m48s to 9m51s, illustrates this point. To mark the material, the subject must also hold the material and was discussing what he was doing.

	45	16	
	48	13, 16, 8	
	51	13, 16, 8	
	54	16, 8	
	57	16	

Table 12 – Example of Code Subsumption

It would appear that increasing the number of pupils could potentially increase the number of observable behaviours during the task. It would also appear that the instrument is capable of showing up this increased level of complexity. Additionally, consideration must also be given to the code for 'Discussion', which so often forms the third in a given sample. As the discussion will be recorded via the recorders in the main study, there is little point in noting discussion that accompanies another process. Instead, the discussion code will be used to indicate that this is the only behaviour being undertaken by the subjects.

Overall, the instrument would appear to afford a good level of accuracy, the extent of which is limited by the sampling interval, the researchers ability to make judgements within this interval and, the degree of relatedness of the behaviours being observed.

9.5 Format of Data Recording

The amended observational schedule represented a significant improvement over that used in the first pilot study. The fact that the observational codes were listed at the top helped significantly, however, attempts should be made to have them printed rather than had written in the main study.

Recording the raw data in a vertical column instead of left to right involved more man-handling of the clip-board during the observation but, overall, worked very well. There was a greater amount of space for codes, a column indicating time and ample room for additional notes and situational factors to be recorded. This should be included and further refined for the main study. There was no reason found to suggest that numerical codes for recording behaviours were problematic.

9.6 Situational Factors

There were a larger number of situational factors observed during this study. They were either in the form of eye-contact with the researcher or, as with those noted at the very end, the subject questioning the researcher. All situational factors arose from the same boy. Those instances of eye contact happened under two sets of circumstances. The first was when the boys were listening to the teacher who was addressing either just them or the class as a whole. The second was when he was watching and waiting for the other boy to finish chiselling. Both are instances where he was not as engaged with the task as he could be.

At the end, the boy asked how good I thought their plane was. This happened while the teacher was instructing them on how to finish up and return the tools to their places.

All of these suggest that situational factors may arise more frequently when the group members are not as engaged with the task as they could be. It should also be noted that the two boys participating in this observation knew the researcher prior to this study. These factors should continue to be accounted for in the main study.

10. Recommendations

As a result of the results and discussion of the above study, the following recommendations can be made and applied to subsequent studies.

(1) The time interval for making observations should remain three seconds.

(2) The observational schedule used should record behaviours from top to bottom and, where possible, have the codes printed at the top.

(3) The use of a timer helps regulate pace during the first few minutes of observation.

(4) Time at 3-second intervals should be printed on the observational schedule.

(5) The researcher must ensure that behaviours are well-defined and that codes are very familiar prior to the observation taking place.

(6) Researcher should be aware that increasing the number of pupils in a group would potentially increase the number of simultaneous observable behaviours.

Appendix 6
Teacher Questionnaire

Teacher Questionnaire – Situational Factors / Observer Effects

If you felt there was a difference in the way pupils answered questions, how would you describe it?

____

____

____

If you saw a difference in which pupils answered questions, how would you describe it?

____

____

____

If you felt there was a difference in how attentive the class were, how would you describe it?

____

____

____

Was the overall behaviour of the class better, the same or worse than normal?

Better   The Same   Worse

Were there any other characteristics or events you observed that were different from normal?

____

____

____

Appendix 7
Pupil Questionnaire 1

What we did to solve the problem…. **Group :**

What did you do with the straws?
What did you do with the cocktail sticks?
What did you do with the thread?
What did you so with the strips of plastic?
What did you do with the sheets of paper?

What did you do with the sheet of card?

Appendix 8
Pupil Questionnaire 2

Part A

THESE QUESTIONS ARE ABOUT THE WHOLE STRUCTURES PROJECT

For each, answer by circling one of the three options.

Q1: Did you enjoy working on the bridge project?

Yes	***Unsure***	***No***

Q2: Did you learn something new?

Yes	***Unsure***	***No***

Q3: Did you feel you should answer questions differently because the researcher was there?

Yes	***Unsure***	***No***

Part B

THESE QUESTIONS ARE ONLY ABOUT THE TWO PERIODS YOU SPENT BUILDING YOUR BRIDGE.

Read each statement and circle the word that shows how much you agree with it.

Q4: 'During the **first** period, I did **not** like being observed by the **researcher**.'

Strongly Agree	***Agree***	***Unsure***	***Disagree***	***Strongly Disagree***

Q5: 'During the **second** period, I did **not** like being observed by the **researcher**.'

Strongly Agree	***Agree***	***Unsure***	***Disagree***	***Strongly Disagree***

Q6: 'During the **first** period, I did **not** like being recorded by the **tape machine**.'

Strongly Agree	***Agree***	***Unsure***	***Disagree***	***Strongly Disagree***

Q7: 'During the **second** period, I did **not** like being recorded by the **tape machine.**'

Strongly Agree	***Agree***	***Unsure***	***Disagree***	***Strongly Disagree***

Finally, circle an option to complete the following statement:

Q8: When the tape machine was recording, I think I:

Talked Less	***Talked The Same Amount***	***Talked More***

Thank you very much for your time and I hope you enjoyed learning about structures and cantilevers.

Appendix 9

Results of Unit Content Observation

Structures Unit Part 1: Bridges (Content Covered)				
Content Indicator	**Description**	**Class 1**	**Class 2**	**Class 3**
1.1	Introduction to Bridges	1	1	1
1.2	Introduction to Beam Bridges	1	1	1
1.2.1	Weakest Bridge	1	1	1
1.2.2	Smallest Span	1	1	1
1.2.3	Beam Bridge Examples	1	1	1
1.3	Introduction to Arch Bridges	1	1	1
1.3.1	Very Strong	1	1	1
1.3.2	Small to Medium Span	1	1	1
1.3.3	Arch Bridge Examples	1	1	1
1.4	Introduction to Suspension Bridges	1	1	1
1.4.1	Very Strong	1	1	1
1.4.2	Large Span	1	1	1
1.4.3	Suspension Bridge Examples	1	1	1
1.5	Introduce Pupil Task	1	1	1

Structures Unit Part 2: Compression & Compression (Content Covered)				
Content Indicator	**Description**	**Class 1**	**Class 2**	**Class 3**
2.1	Introduction to Tension	1	1	1
2.1.1	Definition of Tension	1	1	1
2.1.2	Tension Examples	1	1	1
2.2	Introduction to Compression	1	1	1
2.2.1	Definition of Compression	1	1	1
2.2.2	Compression Examples	1	1	1
3.1	Different Materials in Tension & Compression	1	1	1
3.2	Introduce Pupil Task	1	1	1

Structures Unit Part 3: Ties & Struts (Content Covered)				
Content Indicator	**Description**	**Class 1**	**Class 2**	**Class 3**
4.1	Introduction to Tension & Compression Inside Bridges	1	1	1
4.1.1	Class Example – Beam Bridge	1	1	1
4.1.2	Beam Bridge – Deck	1	1	1
4.1.3	Beam Bridge – Supports	1	1	1
4.1.4	Member in Tension – Tie	1	1	1
4.1.5	Member in Compression – Strut	1	1	1
5.1	Introduce C&T in the Suspension Bridge	1	1	1
5.1.1	Introduce Pupil Task	1	1	1

Structures Unit Part 4: Triangulation (Content Covered)				
Content Indicator	**Description**	**Class 1**	**Class 2**	**Class 3**
6.1	Introduce Triangulation	2	2	1
6.1.1	Rigidity / Stability / Strength	2	2	1
6.1.2	Introduce Pupil Task	2	2	1

Structures Unit Part 5: Cantilevers & Turning Moments (Content Covered)				
Content Indicator	**Description**	**Class 1**	**Class 2**	**Class 3**
7.1	Introduce Cantilever Bridge	2	2	2
7.1.1	Definition of Cantilever	2	2	2
7.1.2	Examples of Cantilevers & Cantilever Bridges	2	2	2
8.1	Introduce Turning Moments	2	2	2
8.1.1	Turning Force at Points Along Cantilever Arm	2	2	2
8.1.2	Introduce Pupil Task	2	2	2
9.1	*Recapitulate*	2	2	2

Appendix 10
Breakdown of Sample Time

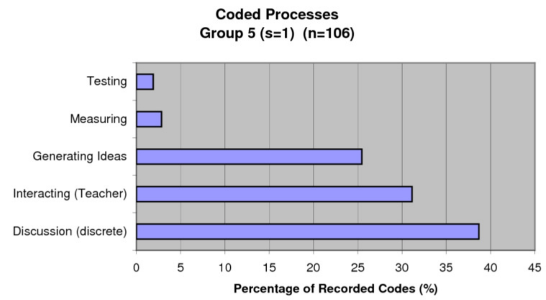
		S=1	S=2	S=3	S=4	S=5	S=6	S=7	End		
School 1	(Session 1)	0.00-4.42	5.03-9.39	10.00-14.42	15.03-19.42	20.03-24.45	25.06-29.39	30.00-34.39	35.00-37.30		
		S=8	S=9	S=10	S=11	S=12	S=13	S=14	S=15	End	
School 1	(Session 2)	0.00-3.24	3.45-7.18	7.39-11.06	11.27-14.57	15.18-18.36	18-57-22.27	22.48-26.06	26.27-29.42	30.03-33.30	

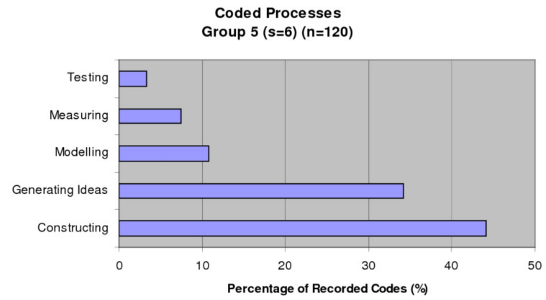
		S=1	S=2	S=3	S=4	S=5	S=6	S=7	S=8	S=9	End
School 2	(Session 1)	0.00-3.36	4.00-7.39	8.00-11.36	12.00-15.36	16.00-19.36	20.00-23.36	24.00-27.36	28.00-31.36	32.00.35.36	36.00-37.00
		S=10	S=11	S=12	S=13	S=14	S=15	S=16	S=17	S=18	End
School 2	(Session 2)	0.00-3.36	4.00-7.39	8.00-11.39	12.00-15.36	16.00-19.39	20.00-23.39	24.00-27.36	28.00-31.39	32.00-33.54	34.00+

		S=1	S=2	S=3	S=4	S=5	S=6	S=7	End		
School 3	(Session 1)	0.00-4.36	4.57-9.36	9.57-14.30	14.51-19.39	20.03-24.39	25.00-29.39	30.00-34.33	34.54-39.48		
		S=8	S=9	S=10	S=11	S=12	S=13	End			
School 3	(Session 2)	0.00-4.36	4.57-9.36	9.57-14.39	15.00-19.42	20.03-24.33	24.54-29.36	29.57-34.30			

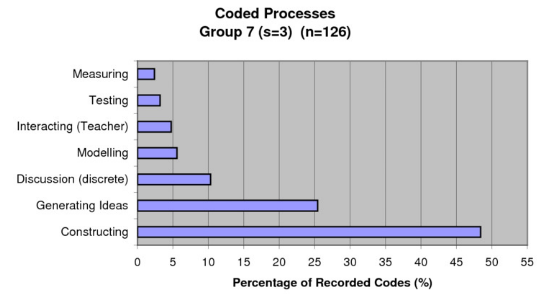
Appendix 11
Results of Structured Observation (Dyad 1)

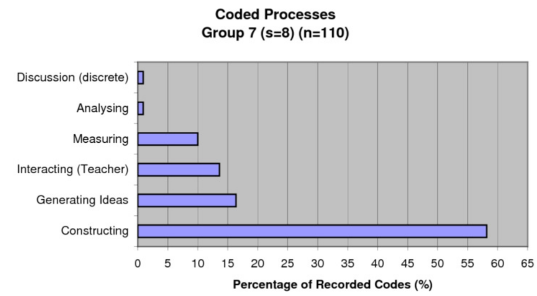
Group 5 Session 1



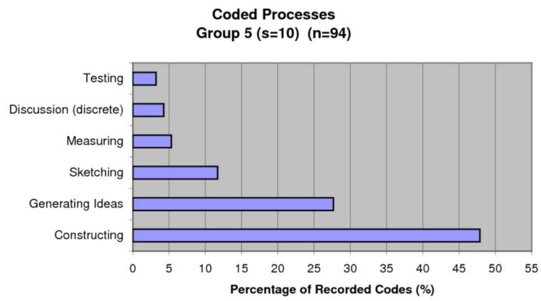


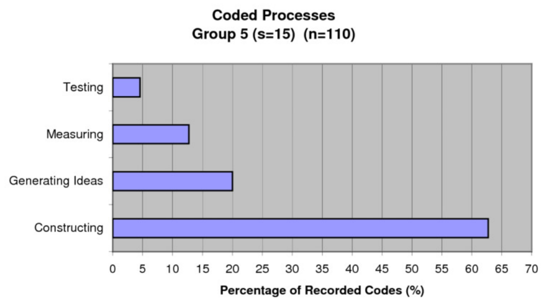
Group 7 Session 1



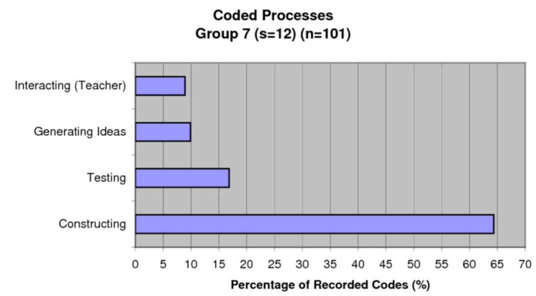


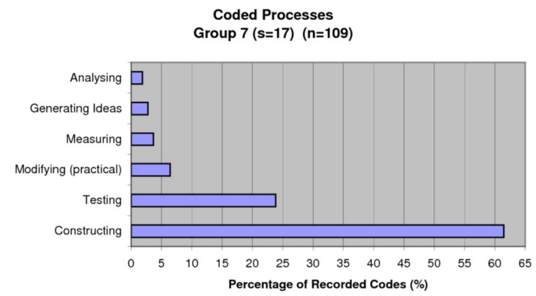
Group 5 Session 2





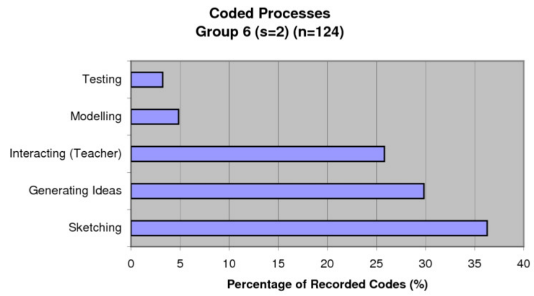
Group 7 Session 2

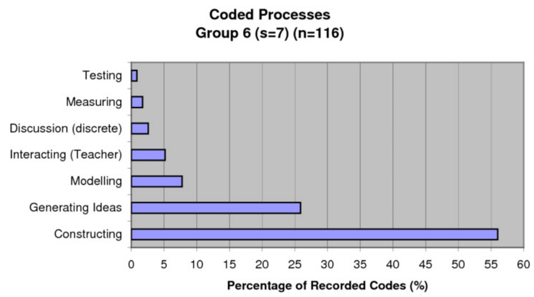




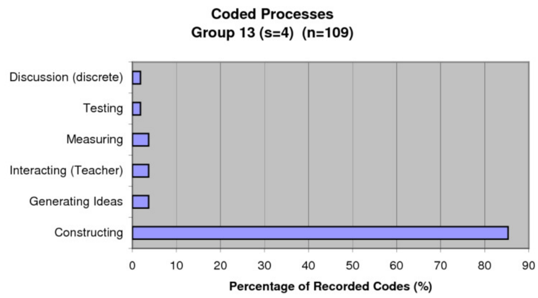
Appendix 11
Results of Structured Observation (Dyad 2)

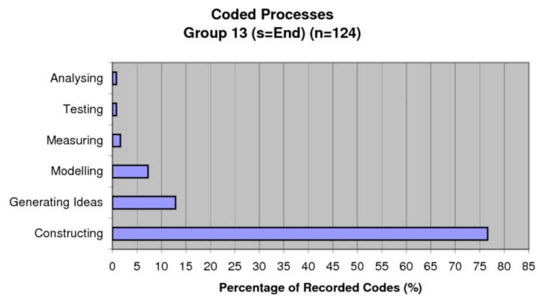
Group 6 Session 1



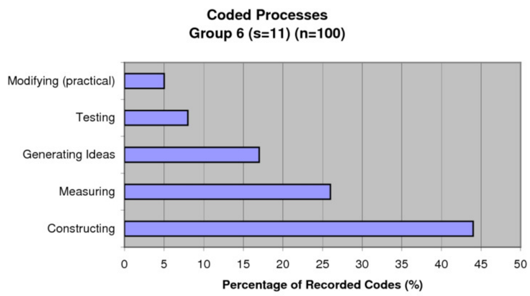


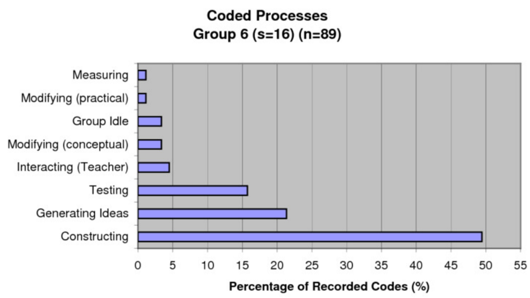
Group 13 Session 1



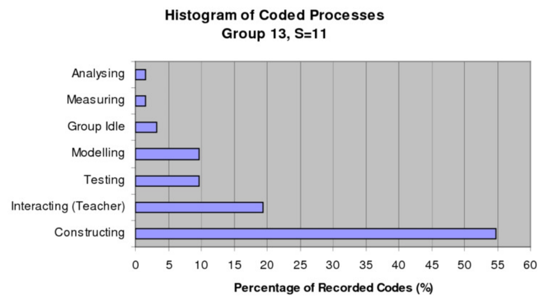


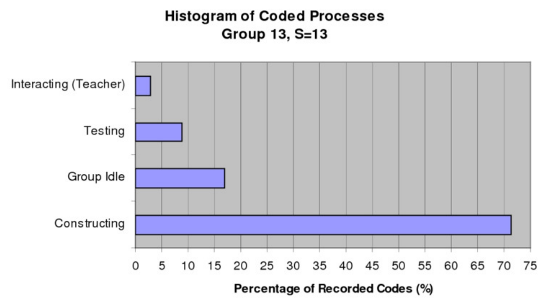
Group 6 Session 2





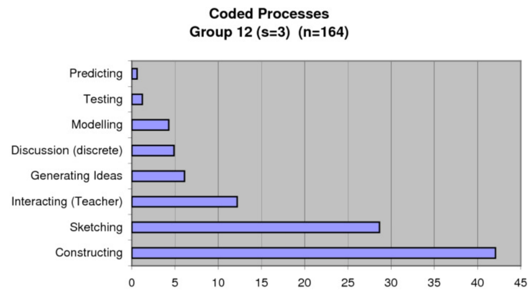
Group 13 Session 2

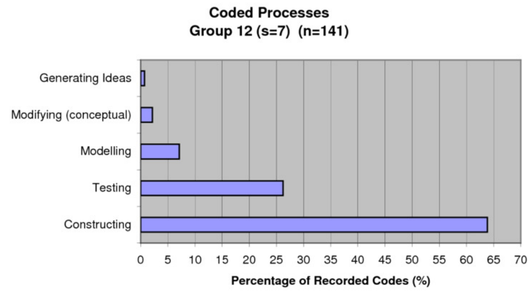




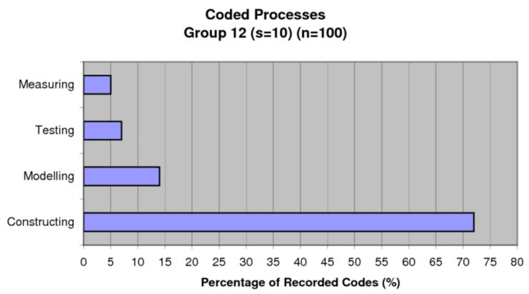
Appendix 11
Results of Structured Observation (Dyad 3)

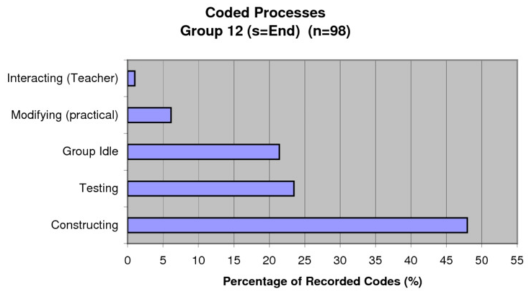
Group 12 Session 1



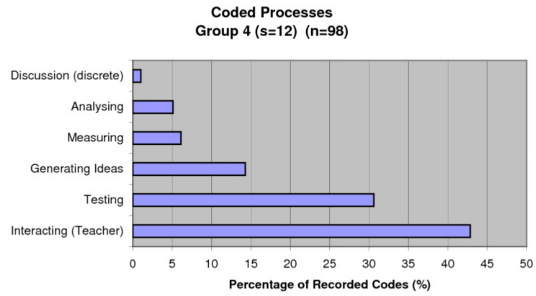


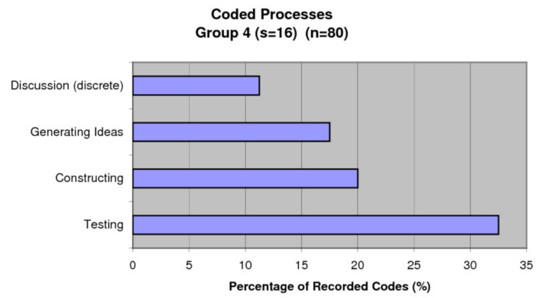
Group 12 Session 2



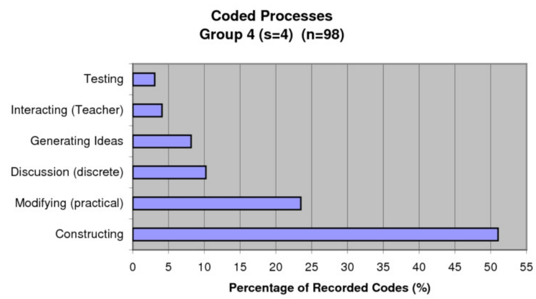


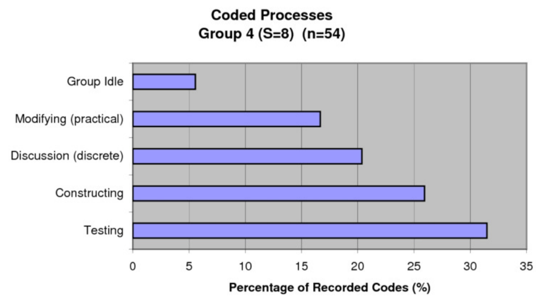
Group 4 Session 2





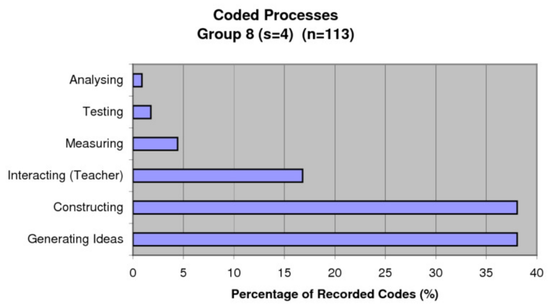
Group 4 Session 1

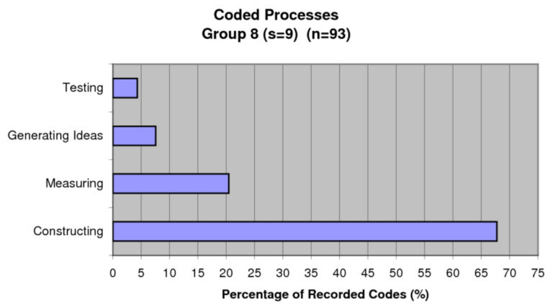




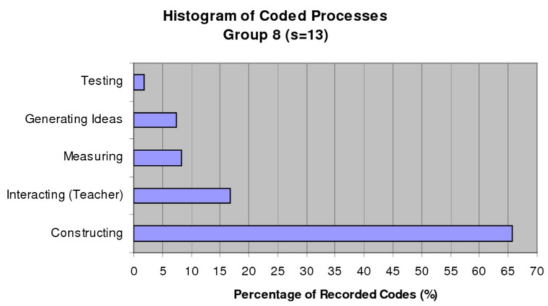
Appendix 11
Results of Structured Observation (Dyad 4)

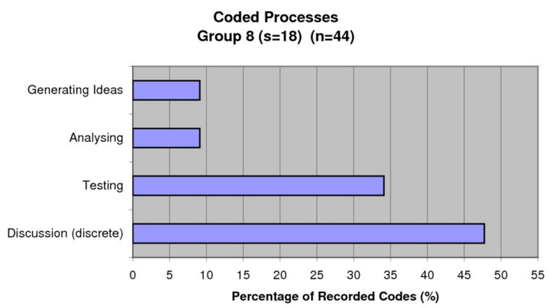
Group 8 Session 1



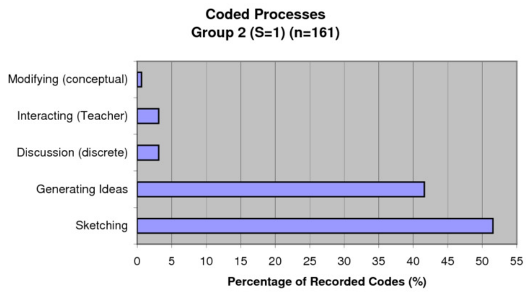


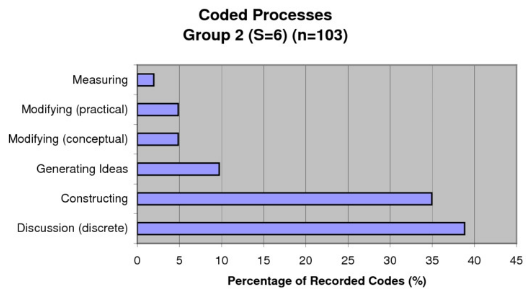
Group 8 Session 2



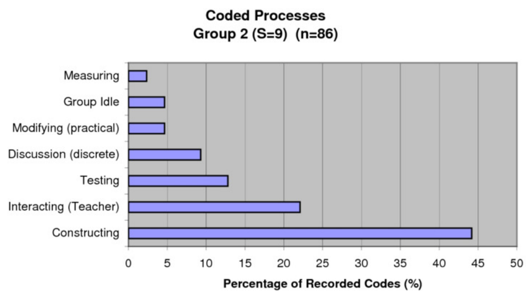


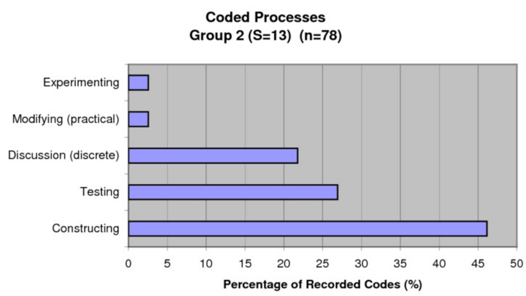
Group 2 Session 1



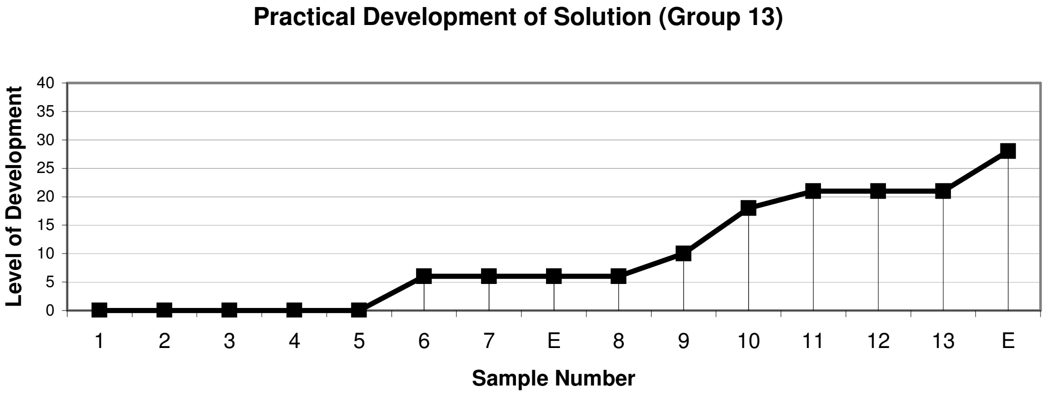


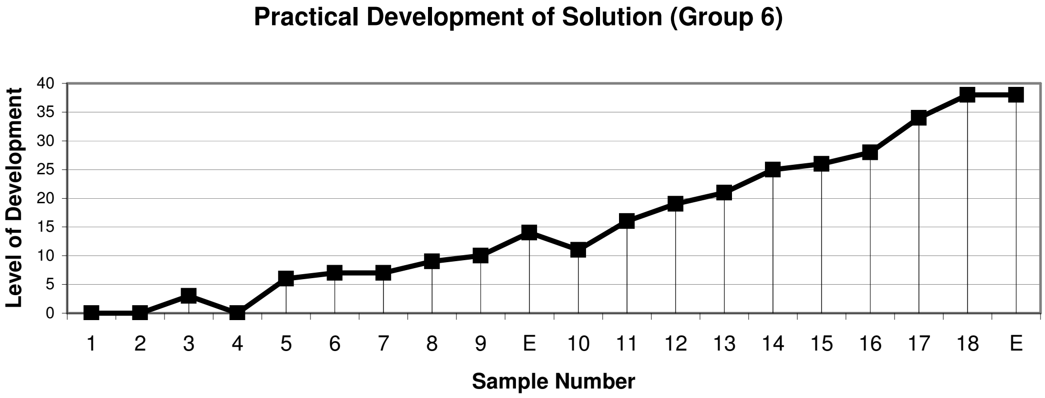
Group 2 Session 2



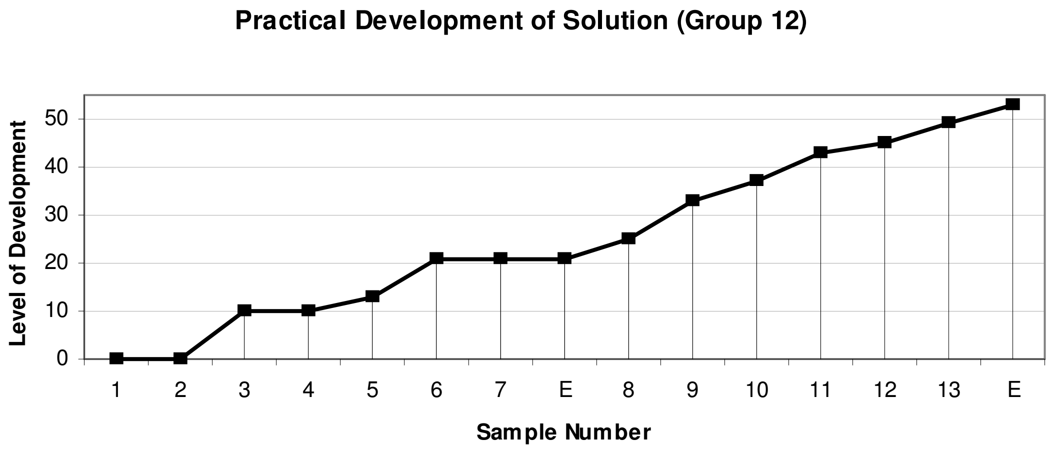


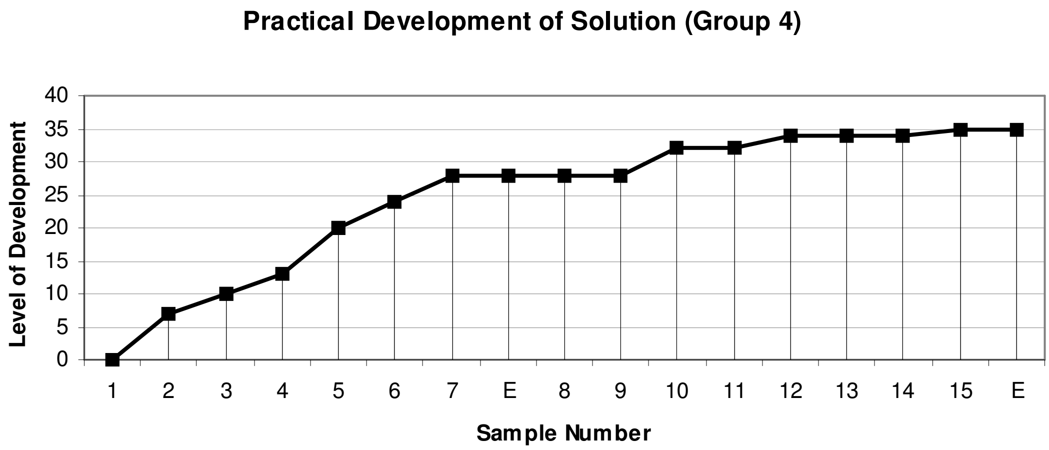
Appendix 12
Solution Development Plots (Dyad 2)



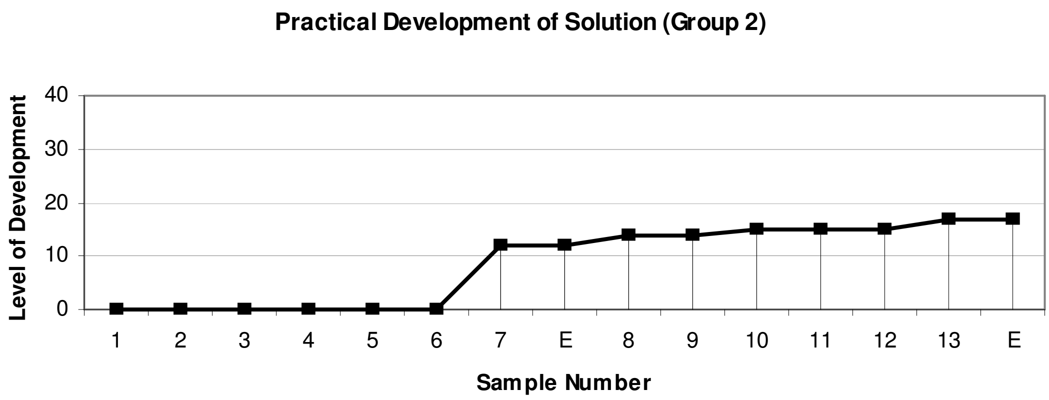


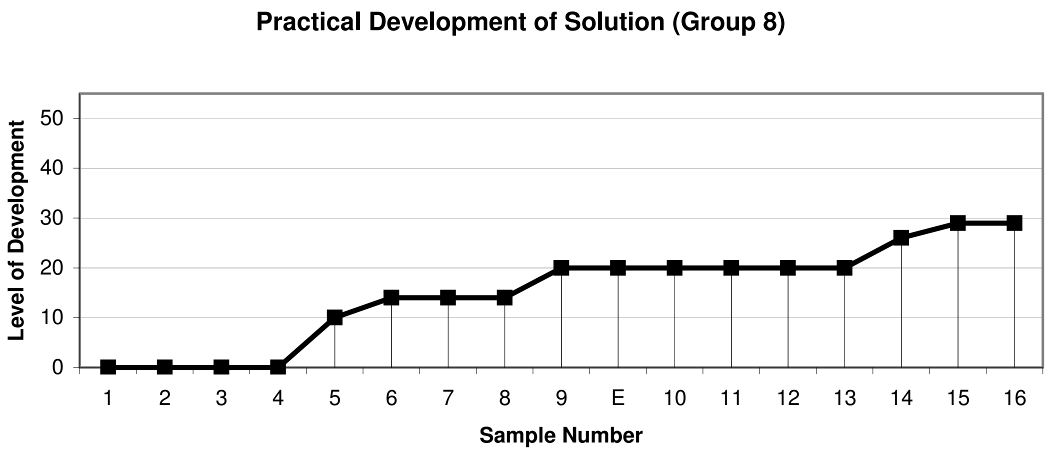
Appendix 13
Solution Development Plots (Dyad 3)





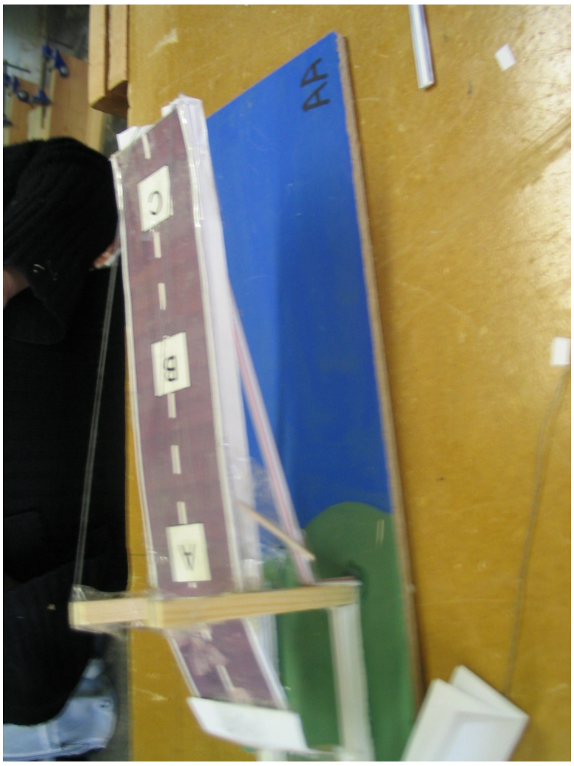
Appendix 14
Solution Development Plots (Dyad 4)

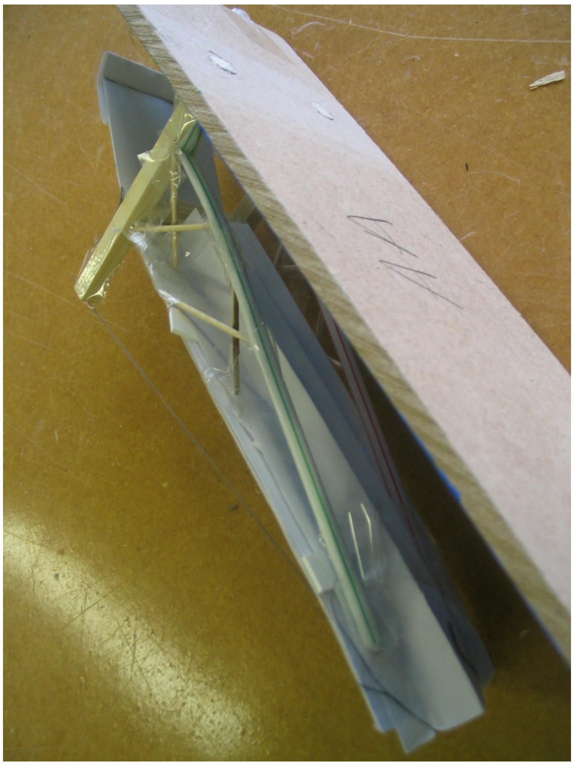




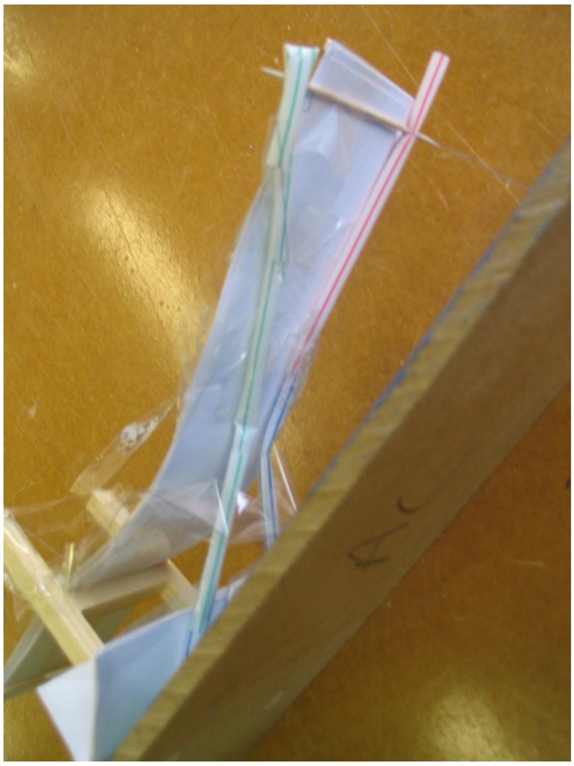
Solution Photos (Dyad 1)

GROUP 5 (Good)



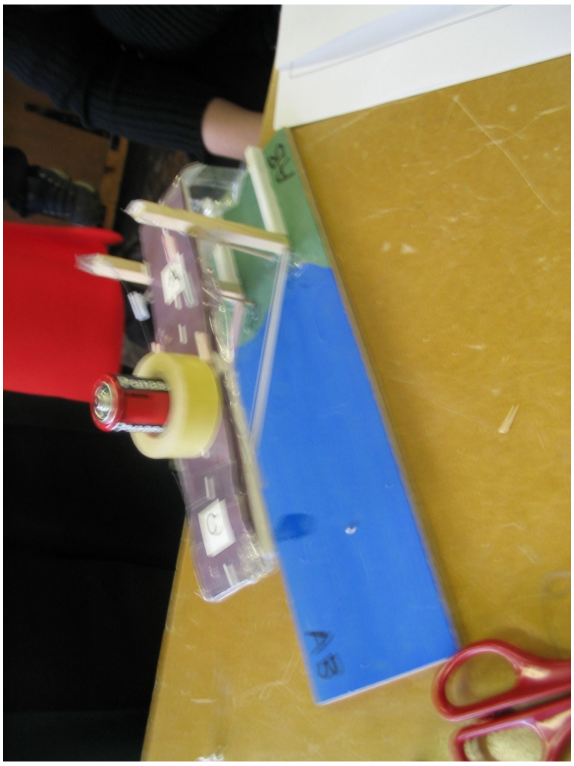


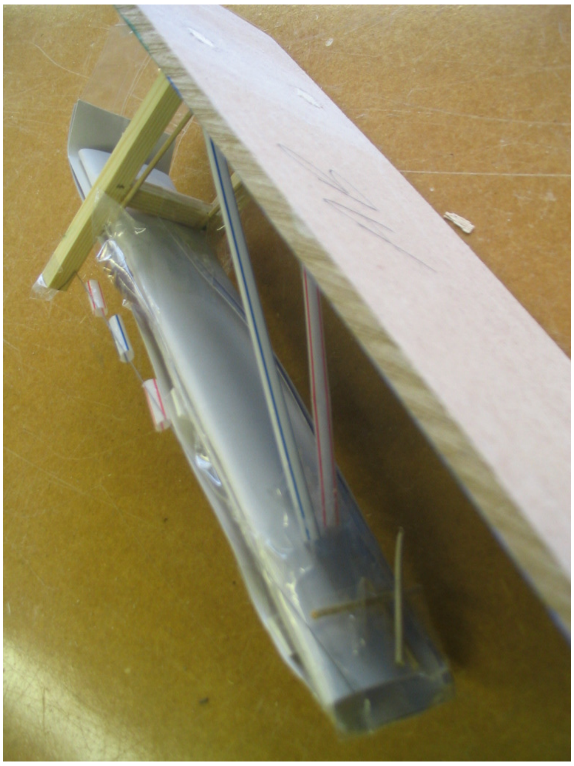
GROUP 7 (Poor)



Appendix 16
Solution Photos (Dyad 2)

GROUP 6 (Good)

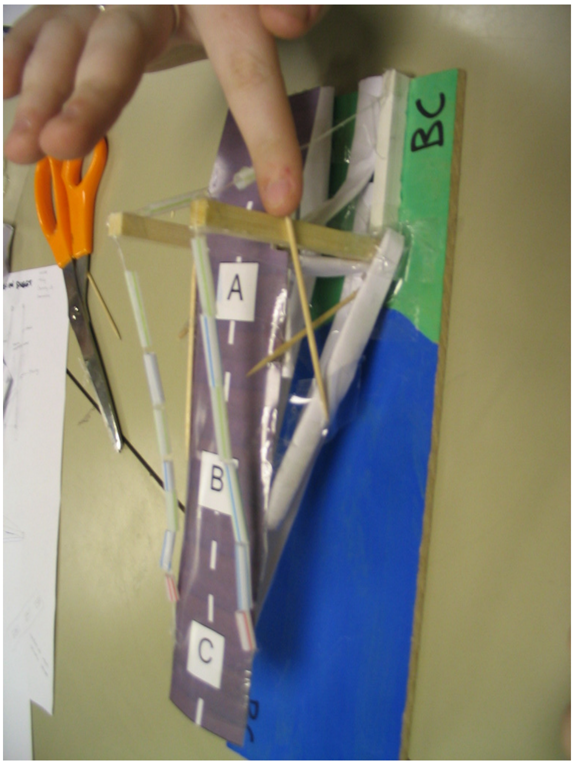


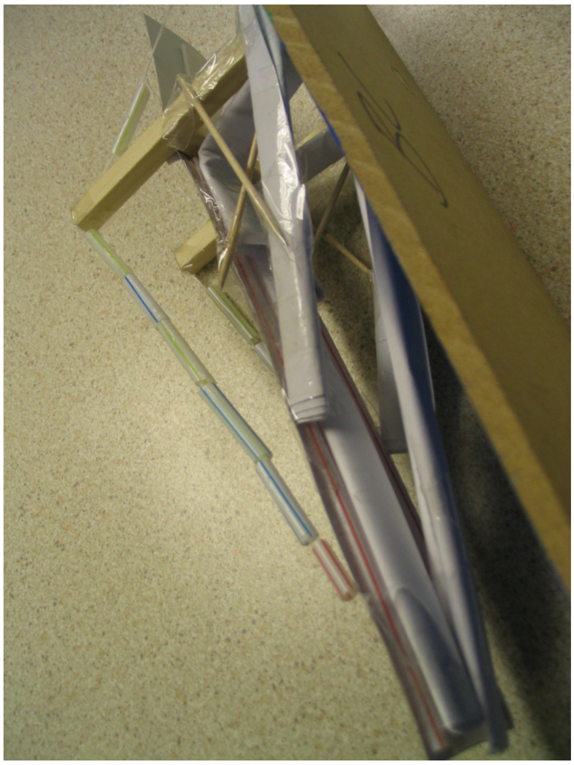


GROUP 13 (Poor)

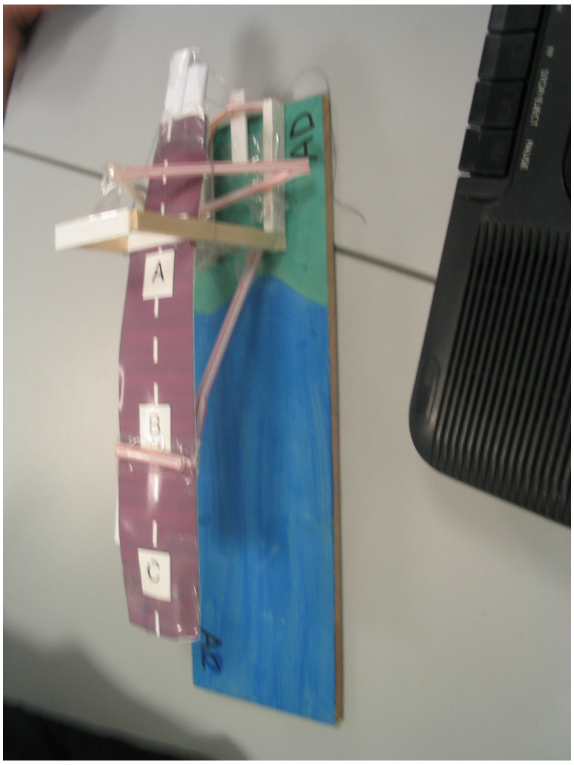
Appendix 17
Solution Photos (Dyad 3)

GROUP 12 (Good)





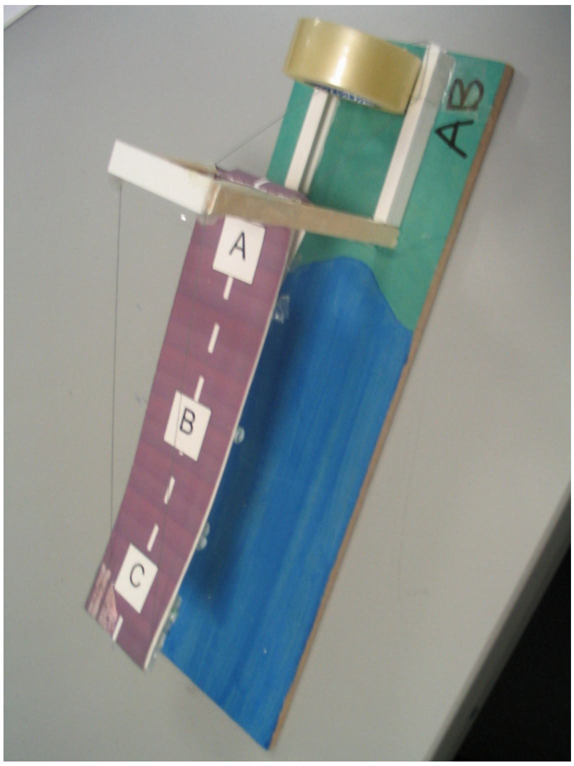
GROUP 4 (Poor)



Appendix 18
Solution Photos (Dyad 4)

GROUP 8 (Good)

GROUP 2 (Poor)



Appendix 20
Delphi Results: Face Validity Analysis

Analysis of Expert Reasons for Solution Categorisation

This analysis will two aspects of the reasoning provided. The first is the extent to which the reasons provided are supported by the information given, and the second is to summarise the aspects that experts have considered to be indicative of a good or poor solution and produce a 'composite reason'. This will be done for those solutions that have been categorised as good and poor as well as any unusual or unexpected cases.

Validity Key:

High: All the components of the reasons provided can be substantiated by the information given to the experts.

Medium: Some of the components of the reasons can be substantiated by the information given and some cannot.

Low: None of the components of the reasons provided can be substantiated by the information given.

Round 1

Solution 5 as BEST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail in the reason given.	Well constructed, use of triangulated frame to support road surface, use of triangulated section to support road surface.
2	High		Use of triangulation, triangulated paper section.
3	High		Support structure.
4	High		Triangulated frame to support road, thread in tension and plastic strips (rigidity of road surface).
5	High	Good level of detail.	Plastic strips across the road surface, thread in tension, triangulated paper section, triangulated frame.
6	Medium	Two components are given: ‘looks well-constructed’ and ‘I like the drawing’. The photograph can substantiate the first, but it is unclear what is meant by the second.	Well constructed.
7	N/A		
8	High		Bracing (triangulated frame), folded paper section.

Part B: Summary of Reasons:

1. Bridge is well constructed
2. Makes good use of triangulation in cocktail stick frame and in supporting the road surface.
3. Deflection minimised by thread in tension.
4. Rigidity of road enhanced with plastic strip cross-supports.

Solution 6 as BEST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail in the reason given.	Good design, looks strong, may have unnecessary elements (cut straws).
2	N/A		
3	N/A		
4	High	Good level of detail.	Rigid road surface (rolled card, cocktail sticks and plastic to re-enforce). Thread in tension to counter deflection.
5	High	Good level of detail.	Thread to end of cantilever, plastic strips, card and straw to support (road).
6	Medium	'Shown holding a load' does support the idea of good strength and is supported by the photograph but 'drawing was not explicit' suggests confusion about the information provided.	Shown holding load.
7	High	Good level of detail.	Cantilever supported in tension and compression, good box section rigidity, anchor arm tensioned to group (no strut).
8	High		Reasonable support provided on the underside.

Part B: Summary of Reasons:

1. Good design (although may have some unnecessary elements/only tensile support for anchor arm)
2. Cantilever both string and rigid.
3. Tensile support extends to the end of the cantilever.
4. Good compressive support underneath to minimise deflection.

Solution 7 as POOREST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail in the reason given.	Not enough support at rear, straw support weakened at joint.
2	High		Covered in selotape, no tension on threads.
3	N/A		
4	High	Good level of detail.	Weakness in straw supports, some reinforcement with cocktail sticks.
5	High		Uneven surface, not rigid, weak triangulation.
6	Medium	This concept is supported generally by both the drawings and photograph although validity is limited due to lack of specificity in the reason given.	Obvious weaknesses.
7	High		Material problems in tension and compression, poor build quality
8	High	Good level of detail.	Good conceptual design, poor construction has lowered the integrity.

Part B: Summary of Reasons:

1. Good conceptual basis, with some weaknesses, was lost due to poor build quality.
2. Road surface was not rigid.
3. Road surface was uneven.
4. Obvious weaknesses in the joints of the supporting structure.
5. No support at the rear of the bridge.
6. Material issues in both tension and compression.

Solution 13 as POOREST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail in the reason given.	Structure unsound, unnecessary members, insufficient support at rear.
2	High		No flat surface, collapsed.
3			Poorly thought out compressive supports.
4	N/A		
5	High		Structure collapsed.
6	High		Structure collapsed.
7	N/A		
8	Medium	'Clumsy design' is supported by the photographs more than the configuration drawings.	Clumsy design.

Part B: Summary of Reasons:

1. Appears structurally unsound and has collapsed.
2. No flat road surface.
3. Compressive support poorly thought out.
4. Unnecessary members.
5. Insufficient support at the rear of the structure.

Round 2

The first section of this maps any shifts in expert judgement between the first and second rounds.

Shifts in judgement when considering which solutions are the best:

Expert	New Solution Voted for in Round 2
1*	Solution 12
2	(No shift)
3	(No shift)
4	(No shift)
5*	Solution 12
6	(No shift)
7*	Solution 9
8*	Solution 8

There were four shifts in judgement identified here.

Shifts in judgement when considering which solutions are the poorest:

Expert	New Solution Voted for in Round 2
1	(No shift)
2*	Solution 2
3	(No shift)
4	(No shift)
5*	Solution 4
6	(No shift)
7	(No shift)
8*	Solution 2

There were three shifts in judgement identified here.

Experts 5 and 8 shifted judgement in both considering the best and worst solutions.

Additional Notes:
Solution 8 received 5 votes in the 1st round and this dropped to 4 in the 2nd. Only three of the experts maintained this group as an example of the best between rounds and the fourth vote was from a different expert.

Although solution 12 ultimately gains a consensus level of 50%, it has gained one vote between rounds 1 and 2.

Solution 8 as BEST

Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail in the reason given. Expert stated that they trend to agree with the other positive comments made for this solution in round 1.	Corrugated card column at rear, good road re-enforcement, not overly complex.
2	Medium	Insufficient detail to determine exactly what is meant by: ‘good mix of tension and compression’. It does suggest, however, that the solution has made good use of each.	Good mix of tension/compression, build quality, simplicity.
3	N/A		
4	N/A		
5	High	Good level of detail.	Best use of materials and well supported road surface.
6	N/A		
7	N/A		
8	High		Rigid road surface supported in tension and compression.

Part B: Summary of Reasons:

1. Good use of corrugated card column at rear.
2. Good road surface re-enforcement.
3. Road surface well supported in both tension and compression.
4. Not overly complex.
5. Good build quality.
6. Best use of materials.

Solution 12 as BEST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good level of detail. Stated that answer changed based upon the reasons given by other Delphi members.	Well-constructed, strong, but may have some redundancy & tie/strut confusion.
2			
3	N/A		
4	High		Supported above and below, good bracing.
5	High		Support from card and cocktail sticks (reasonable), string suspension.
6	N/A		
7	N/A		
8	High		Supported well from above and below.

Part B: Summary of Reasons:

1. Appears strong and well constructed (with some member redundancy).
2. Road surface well braced and supported from above and below.

Solution 2 as POOREST
Part A: Assessment of validity of justifications:

Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	High	Good detail. Agrees with other experts that the lack of triangulation is a major flaw. No change from reasons given in first round.	Weak, only supported above by thread, only thread at rear suggests risk of a lot of movement under loading. Lack of triangulation.
2			Over-reliance on two members on tension to support the road.
3			
4	High		No triangulation and the road section is not secured.
5	High		Little to no triangulation, poor quality structure.
6			
7	High	Comments may suggest a degree of uncertainty about the purpose of the configuration drawings.	More of a poor quality suspension bridge, concepts in drawing good, build quality poor.
8	High		Poor structural strength, likely to have poor rigidity.

Part B: Summary of Reasons:

1. Lack of triangulation.
2. Limited support for the cantilever in the form of thread.
3. Road surface not properly secured
4. Poor overall build quality.
5. Low structural strength.
6. Likely to have poor rigidity.

Solution 4 as POOREST
Part A: Assessment of validity of justifications:

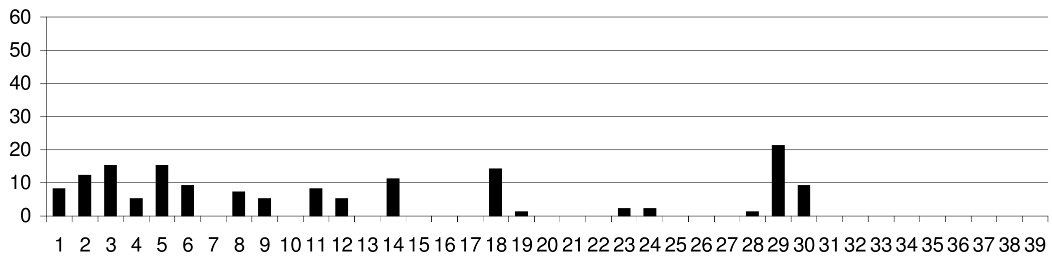
Expert	Assessment of Validity	Comments	Themes/Aspects Identified
1	N/A		
2	High		Poorly supported road surface – would struggle under loading at C.
3	N/A		
4	High		Poorly supported road, little triangulation, small amount of deflection reduced with thread.
5	High	Good level of detail. Agrees with the comments from other experts about triangulation.	Triangulation in the wrong place, uneven road surface, road dips at the end, overall structure is less sound than others.
6	High		Some basic structural understanding shown but poorly executed in practise.
7	Medium	For part of the reason given, it is unclear as to what is meant. Difference between drawing and solution commented on. May again indicate lack of clarity about the purpose of the configuration drawings.	Build not representative of drawing.
8	N/A		

Part B: Summary of Reasons:

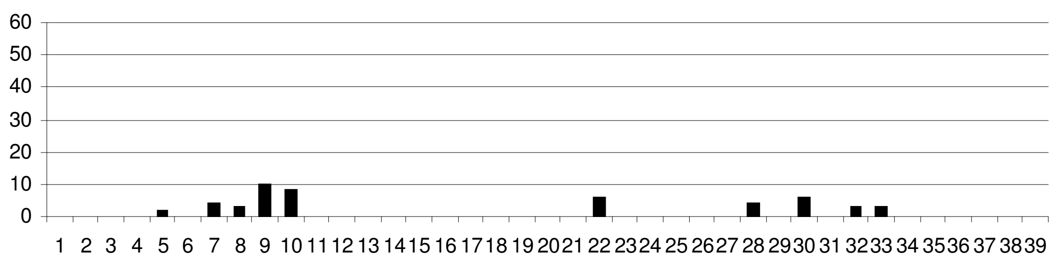
1. Road surface poorly supported, although deflection reduced to some degree with thread.
2. Triangulation in the wrong place.
3. Road surface is uneven and dips at the end.
4. Some basic structural understanding, but solution was poorly executed and seen to be less structurally sound than the other solutions.

Appendix 21
Distribution of Negative Managements Traits (Group 7)

Process Management: Negative Indicators (Group 7 - Session 1)



Process Management: Negative Indicators (Group 7 - Session 2)



List of References

Alamäki, A. (1999). Technology education in the Finnish primary schools. Journal of Industrial Teacher Education, 11(1).

Allison, H.E. (2004). Kant's transcendental idealism. Yale University Press.

Amabile, T.M. (1998). How to kill creativity. Harvard business review, 76(5), pp.76–87.

Anderson, J.R. (1983). The architecture of cognition. Cambridge: Harvard University Press.

Anning, A., Jenkins, E. and Whitelaw, S. (1996). Bodies of knowledge and design-based activities. [online]. Available from: https://dspace.lboro.ac.uk/dspace/handle/2134/1473.

Argyle, M. (1972). Anlaysis of the behaviour of an interactor. In A. Morrison & D. McIntyre, eds. The Social Psychology of Teaching. London: Cox & Wyman Ltd.

Ausubel, D.P. (1970). Reception learning and the rote-meaningful dimension. In E. Stones, ed. Readings in Educational Psychology. London: Methuen & Co Ltd.

Baddeley, A. (1986). Working memory (Oxford Psychology Series No. 11). New York: Oxford University Press.

Baker-Sennett, J., Matusov, E., Rogoff, B. and Reese, H. W. (1993). Planning as developmental process. Advances in child development and behavior, 24, pp.253–281.

Bartley, M. and Blane, D. (1994). Commentary: Appropriateness of deprivation indices must be ensured. BMJ, 309(6967), p.1479.

Bazeley, P. (2004). Issues in mixing qualitative and quantitative approaches to research, in R. Buber, J. Gadner, & L. Richards (eds.) Applying qualitative methods to marketing management research (pp. 141-156). Basingstoke, UK: Palgrave Macmillan.

Bennett, N. and Cass, A. (1989). The effects of group composition on group interactive processes and pupil understanding. British Educational Research Journal, 15(1), pp.19–32.

Bereiter, C. and Scardamalia, M. (2005). Beyond Bloom's taxonomy: Rethinking knowledge for the knowledge age. Fundamental Change, pp.5–22.

Blatchford, P., Baines, E., Rubie-Davies, C., Bassett, P. and Chowne, A. (2006). The effect of a new approach to group work on pupil-pupil and teacher-pupil interactions. Journal of Educational Psychology, 98(4), p.750.

Bloom, B.S., Engelhart, M. D., Furst, E. J., Hill, W. H. and Krathwohl, D. R. (1956). Taxonomy of educational objectives: Handbook I: Cognitive domain. New York: David McKay, 19, p.56.

Blumenfeld-Jones, D. (1995). Fidelity as a criterion for practicing and evaluating narrative inquiry. International Journal of Qualitative Studies in Education, 8(1), pp.25–35.

Bong, S.A. (2002). Debunking myths in qualitative data analysis. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research.

Boulton, D. and Hammersley, M. (2006). Analysis of unstructured data. In: Sapsford, R. and Jupp, V. eds. Data Collection and Analysis. London: Sage, pp. 243–259.

Brannen, J. (2005). Mixing methods: The entry of qualitative and quantitative approaches into the research process. Int. J. Social Research Methodology, 8(3), pp.173–184.

Bredo, E. (1994). Cognitivism, situated cognition, and Deweyian pragmatism. In Proceedings of the Fiftieth Annual Meeting of the Philosophy of Education Society.

Breuer, F., Mruck, K. and Wolff-Michael, R. (2002) Subjectivity and Reflexivity: An Introduction. Forum: Qualitative Social Research, 3(3). [online]. Available from: http://www.qualitative-research.net/fqstexte/ 3-02/3-02hrsg-e.htm.

Brown, J.S., Collins, A. and Duguid, P. (1989). Situated cognition and the culture of learning. Educational researcher, 18(1), pp.32–42.

Brown, S.R. (1993). A primer on Q methodology. Operant subjectivity, 16(3/4), pp.91–138.

Bruner, J. (1961). The process of education. Cambridge: Mass: Harvard University Press.

Bruton, D. (2010). Learning creativity and design for innovation. International Journal of Technology and Design Education, 21(3), pp.321–333.

Bryce, T. G. K. & Hume, W. M. (Eds.) (2000). Scottish Education. Edinburgh: Edinburgh University Press.

Bryman, A. (1988). Quantity and quality in social research. Routledge.

Bunge, M. (1966). Technology as applied science. Technology and Culture, 7(3), pp.329–347.

Carpenter, T.P., Ansell, E., Franke, M. L., Fennema, E. and Weisbeck, L. (1993). Models of problem solving: A study of kindergarten children's problem-solving processes. Journal for Research in Mathematics Education, pp.428–441.

Carstairs, V., Morris, R. (1991). Deprivation and health in Scotland. Aberdeen: Aberdeen University Press, 0080379796.

Catrambone, R. and Holyoak, K.J. (1989). Overcoming contextual limitations on problem-solving transfer. Journal of Experimental Psychology: Learning, Memory, and Cognition, 15(6), p.1147.

Cattell, R.B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. Journal of Educational Psychology; Journal of Educational Psychology, 54(1), p.1.

Charmaz, K. (2003). Grounded Theory. In M. Lewis-Beck, A. E. Bryman, & T. F. Liao (Eds). The sage encyclopedia of social science research methods. pp.440-444. London: Sage.

Chugani, H.T. (1998). A critical period of brain development: studies of cerebral glucose utilization with PET. Preventive medicine, 27(2), pp.184–188.

Clancey, W.J. (1995). A tutorial on situated learning. pp.49-70 [online] Available from: http://cogprints.org/323/

Claxton, J.D., Brent Ritchie, J.R. and Zaichkowsky, J. (1980). The Nominal Group Technique: It's Potential for Consumer Research. Journal of Consumer Research, 7(3), pp.308–313.

Cohen, L., Manion, L. and Morrison, K. (2000). Research methods in education, 5th Edition. London: Routledge Falmer.

Compton, V. and Harwood, C. (2003). Enhancing technological practice: An assessment framework for technology education in New Zealand. International Journal of Technology and Design Education, 13(1), pp.1–26.

Conwell, C.R., Griffin, S. and Algozzine, B. (1993). Gender and racial differences in unstructured learning groups in science. International journal of science education, 15(1), pp.107–115.

Corbin, J.M. and Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. Qualitative sociology, 13(1), pp.3–21.

Cropley, D. and Cropley, A. (2009). Recognizing and fostering creativity in technological design education. International Journal of Technology and Design Education, 20(3), pp.345–358.

Cross, R.M. (2005). Exploring attitudes: the case for Q methodology. Health Education Research, 20(2), pp.206–213.

Csikszentmihalyi, M. (1997). Finding flow: The psychology of engagement with everyday life. Basic Books.

Custer, R.L. (1995). Examining the dimensions of technology. International Journal of Technology and Design Education, 5(3), pp.219–244.

Custer, R.L. (1996). Rubrics: An Authentic Assessment Tool for Technology Education. Technology Teacher, 55(4), pp.27–37.

Custer, R.L., Valesey, B.G. and Burke, B.N. (2001). An assessment model for a design approach to technological problem solving.

Cutcliffe, J. R. (2000). Methodological issues in grounded theory. Journal of Advanced Nursing, 31(6). pp.1476-1484.

Davidson, J.E., Deuser, R. and Sternberg, R.J. (1994). The role of metacognition in problem solving. In Metacognition. MIT Press, pp. 207–226.

Davies, T. (1996a). Modelling and creativity in design and technology. IDATER 1996 Conference. Loughborough University.

Davies, D. (1996b). Professional design and primary children. International Journal of Technology and Design Education, 6(1), pp.45–59.

DeGroot, M.H. (1974). Reaching a consensus. Journal of the American Statistical Association, 69(345), pp.118–121.

Delbecq, A., Van de Ven, A. and Gustafson, D. (1975). Group techniques for program planning: a guide to nominal group and Delphi processes. Glenview, Ill: Scott Foresman.

Delgado, M. et al. (1998). Combining numerical and linguistic information in group decision making. Information Sciences, 107(1), pp.177–194.

Denton, H. (1993). The Design and Make Task (DMT): some reflections on designing in schools.

Detterman, D.K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg, eds. Transfer on trial: Intelligence, cognition and instruction. New Jersey: Ablex, pp. 25–38.

Duncker, K. and Lees, L.S. (1945). On problem-solving. Psychological monographs, 58(5), p.i.

Eklund, P., Rusinowska, A. and De Swart, H. (2007). Consensus reaching in committees. European Journal of Operational Research, 178(1), pp.185–193.

Engelhart, M.D. et al. (1956). Taxonomy of educational objectives: The classification of educational goals. B. S. Bloom, ed. New York: David McKay.

Engle, R.W. et al. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. Journal of Experimental Psychology: General, 128(3), p.309.

Erev, I., Bornstein, G. and Galili, R. (1993). Constructive intergroup competition as a solution to the free rider problem: A field experiment. Journal of Experimental Social Psychology, 29, pp.463–478.

Erkip, F., Demirkan, H. and Pultar, M. (1997). Knowledge acquisition for design education. [online]. Available from: https://dspace.lboro.ac.uk/dspace/handle/2134/1451.

Ernest, P. (1995). The one and the many. In J. E. Steffe, L. P. & J. E. Gale, eds. Constructivism in education. New Jersey: Lawrence Erlbaum Associates Inc., pp. 459–486.

Estes, W.K. (1982). Multiple coding and processing stages: A review. Cognitive research in psychology, pp.14–21.

Faux, R.B. (2000). A description of the uses of content analyses and interviews in educational/psychological research. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research.

Feldman, D.H., Csikszentmihalyi, M. and Gardner, H. (1994). A framework for the study of creativity. Changing the world. A framework for the study of creativity, pp.1–45.

Ferré, F. (1995). Philosophy of technology. University of Georgia Press.

Fielding, N.G. and Fielding, J.L. (1986). Linking data: the articulation of qualitative and quantitative methods in social research. Beverly Hills (CA): Sage, pp.41–53.

Finlay, L. and Gough, B. eds. (2003). Reflexivity: A Practical Guide for Researchers in Health & Social Sciences. Oxford: Blackwell Science.

Flick, U. (1992). Triangulation revisited: strategy of validation or alternative? Journal for the theory of social behaviour, 22(2), pp.175–197.

Flowers, J. (1998). Problem solving in technology education: A Taoist perspective. Journal of Technology Education, 10, pp.20–26.

Frensch, P.A. and Funke, J. (1995). Complex problem solving: The European perspective. Lawrence Erlbaum.

Frey, R.E. (1989). A Philosophical Framework for Understanding Technology. Journal of Industrial Teacher Education, 27(1), pp.23–35.

Gagne, R.M. (1966). The leaerning of principles. In E. Stones, ed. Readings in Educational Psychology: Learning and Teaching. New York: Barnes and Noble, Inc., pp. 67–84.

Gall, M. D., Borg, W. R. and Gall, J. P. (2002) Educational research: an introduction, 7th Edition, Allyn & Bacon.

Gardner, H. (1993). Farmes of Mind: The Thoery of Multiple Intelligences. London: Fontana Press.

Gibb, K., Kearns, A., Keoghan, M. MacKay, D. and Turok, I. (1998). Revising The Scottish Area Deprivation Index Volume. The Scottish Office, Central Research Unit, Edinburgh.

Glaser, B.G. (1992): Basics of grounded theory analysis: Emergence versus forcing. Sociology Press, Mill Valley, CA.

Goldman-Rakic, P.S. (2000). Architecture of the prefrontal cortex and the central executive. In M. S. Gazzaniga, ed. Cognitive Neurscience: A reader. Oxford: Blackwell Publishers Ltd., pp. 391–404.

Gordon, T.J. (1994). The delphi method. Futures research methodology, pp.1–33.

Gray, J.R. et al. (2003). Neural mechanisms of general fluid intelligence. Nature neuroscience, 6(3), pp.316–322.

Groot, A.D. (1969). Methodology: Foundations of inference and research in the behavioral sciences. Hague: Mouton.

Gustafson, B.J. and Rowell, P.M. (1998). Elementary Children's Technological Problem Solving: selecting an initial course of action. Research in Science & Technological Education, 16(2), pp.151–163.

Halasz, F.G. and Moran, T.P. (1983). Mental models and problem solving in using a calculator. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems. pp. 212–216.

Halfin, H.H. (1973). Technology: A process approach. PhD Thesis. West Virginia University.

Hamalainen, R.P., Salo, A.A. and Poysti, K. (1992). Observations about consensus seeking in a multiple criteria environment. In System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on. pp. 190–198.

Hamel, R. and Elshout, J.J. (2000). On the development of knowledge during problem solving. European Journal of Cognitive Psychology, 12(3), pp.289–322.

Hammersley, M. (1996). The relationship between qualitative and quantitative research: Paradigm loyalty versus methodological eclecticism. In J. T. E. Richardson (Ed.), Handbook of qualitative research methods for psychology and the social sciences (pp. 89-107). Leicester: BPS Books.

Hammersley, M. (2006). Philosophy's contribution to social science research on education. Journal of philosophy of education, 40(2), pp.273–286.

Hardin, L.E. (2003). Problem-solving concepts and theories. Journal of Veterinary Medical Education, 30(3), pp.226–229.

Harkins, S.G. (1987). Social loafing and social facilitation. Journal of Experimental Social Psychology, 23(1), pp.1–18.

Harrison, B. (2002). Seeing health and illness worlds–using visual methodologies in a sociology of health and illness: a methodological review. Sociology of Health & Illness, 24(6), pp.856–872.

Hayes, J.R. (1981). The complete problem solver. Franklin Institute Press, Philadelphia.

Hayes, J.R. (1989). The complete problem solver. 2nd ed. New Jersey: Lawrence Erlbaum Associates Inc.

Hendley, D. and Lyle, S. (1995). The potential of collaborative group work to increase pupil learning in the implementation of design and technology in the National Curriculum. The Curriculum Journal, 6(3), pp.363–376.

Hennessy, S. and McCormick, R. (1994). The general problem-solving process in technology education. In F. Banks, ed. Teaching and learning technology. London: Routledge, pp. 94–108.

Hennessy, S. and Murphy, P. (1999). The potential for collaborative problem solving in design and technology. International Journal of Technology and Design Education, 9(1), pp.1–36.

Herrera, F., Herrera-Viedma, E. and others. (1996). A model of consensus in group decision making under linguistic assessments. Fuzzy sets and Systems, 78(1), pp.73–87.

Herschbach, D.R. (1995). Technology as knowledge: Implications for instruction. Journal of Technology Education, 7(1).

Hill, A.M. and Anning, A. (2001). Primary teachers' and students' understanding of school situated design in Canada and England. Research in Science Education, 31(1), pp.117–135.

Hill, R.B. (1997). The design of an instrument to assess problem solving activities in technology education. [online]. Available from: http://scholar.lib.vt.edu/ejournals/JTE/v9n1/hill.html.

Hill, R.B. and Wicklein, R.C. (1999). A factor analysis of primary mental processes for technological problem solving.

Hindle, B. (1966). Technology in Early America; Needs and Opportunities for Study.

Von Hippel, E. and Katz, R. (2002). Shifting innovation to users via toolkits. Management science, 48(7), pp.821–833.

Hoepfl, M.C. (1997). Choosing qualitative research: A primer for technology education researchers. Journal of Technology Education, 9(1).

Horn, J.L. and Cattell, R.B. (1967). Age differences in fluid and crystallized intelligence. Acta psychologica, 26, pp.107–129.

Howe, C. (1997). Gender and classroom interaction. SCRE Publications.

Howe, K. and Eisenhart, M. (1990). Standards for qualitative (and quantitative) research: A prolegomenon. Educational researcher, 19(4), pp.2–9.

Hoyles, C. (1985). What is the point of group discussion in mathematics? Educational studies in mathematics, 16(2), pp.205–214.

Hull, C.L. (1934). The concept of the habit-family hierarchy, and maze learning. Part I. Psychological Review, 41(1), p.33.

Hyde, K.L. et al. (2009). Musical training shapes structural brain development. The Journal of Neuroscience, 29(10), pp.3019–3025.

Isaacs, S. and Piaget, J. (1929). The language and thought of the child; Judgment and reasoning in the child; The child" s conception of the world. The Pedagogical Seminary and Journal of Genetic Psychology.

ITEA. (2000). Standards for Technological Literacy: Content for the Study of Technology. Reston, VA: International Technology Education Association.

Jaeggi, S.M., Buschkuehl, M. Jonides, J. and Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences, 105(19), p.682-9.

Johnson, D. W., Maruyama, G., Johnson, R., Nelson, D. and Skon, L. (1981). Effects of cooperative, competitive, and individualistic goal structures on achievement: A meta-analysis. Psychological Bulletin, 89(1), p.47.

Johnson, S.D. (1997). Learning technological concepts and developing intellectual skills. International Journal of Technology and Design Education, 7(1), pp.161–180.

Johnson, S.D. and Chung, S.P. (1999). The effect of thinking aloud pair problem solving on the troubleshooting ability of aviation technician students. Journal of Industrial Teacher Education, 37(1), pp.1–18.

Jonassen, D.H. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? Educational technology research and development, 39(3), pp.5–14.

Jonassen, D.H. (2000). Toward a design theory of problem solving. Educational technology research and development, 48(4), pp.63–85.

Jones, A. (1997). Recent research in learning technological concepts and processes. International Journal of technology and design education, 7(1), pp.83–96.

Jones, A. (1994). Technological problem solving in two science classrooms. Research in Science Education, 24(1), pp.182–190.

Jones, A. and Carr, M. (1994). Student technological capability: Where do we start. SAME Papers 1994, pp.165–186.

Jones, A. and Carr, M. (1992). Teachers' perceptions of technology education: Implications for curriculum innovation. Research in Science Education, 22(1), pp.230–239.

Jones, A., Mather, V. and Carr, M. (1995). Issues in the practice of technology education. University of Waikato, Hamilton: Centre for Science and Mathematics Education Research.

Kahney, H. (1993). Problem solving: Current issues (2nd ed.) Buckingham, England: Open University press.

Kelle, U. (2007). 'Emergence' vs. 'Forcing' of Empirical Data? A Crucial Problem of Grounded Theory Reconsidered. Historical Social Research/Historische Sozialforschung. Supplement. JSTOR. pp.133-156.

Kelley, T. and Hill, R. (2007). Cognitive Processes of Students Solving Technical Problems. [online]. Available from: http://digitalcommons.usu.edu/ncete_cstudies/9/.

Kim, S. (1990). Essence of creativity: A guide to tackling difficult problems. Oxford University Press, USA.

Kimbell, R. (1982). Design Education: The Foundation Years. London & New York: Routledge & Kegan Paul.

Klein, N. and Shragai, Y. (2001). Creativity and the design approach: a proposed module.

Kornwachs, K. (1998). A Formal Theory of Technology? Society for Philosophy and Technology, 4(1).

Kowaltowski, D.C.C.K., Bianchi, G. and Paiva, V.T. (2009). Methods that may stimulate creativity and their use in architectural design education. International Journal of Technology and Design Education, 20(4), pp.453–476.

LaFave, S. (2006). Thinking critically about the ‘subjective’/‘objective’ distinction.

Lave, J. and Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Pr.

Layton, D. (1993). Technology’s Challenge to Science Education. Open University Press.

Lewis, T. (1999). Content or Process as Approaches to Technology Curriculum: Does It Matter Come Monday Morning? Journal of Technology Education, 11(1).

Lewis, T. (2009). Creativity in technology education: Providing children with glimpses of their inventive potential. International Journal of Technology and Design Education, 19(3), pp.255–268.

Liddament, T. (1996). Design and problem-solving. IDATER 1996 Conference, Loughborough University.

Lindqvist, G. (2003). Vygotsky’s theory of creativity. Creativity Research Journal, 15(2-3), pp.245–251.

Linstone, H.A. and Turoff, M. eds. (2002). The Delphi method: Techniques and applications. Addison-Wesley Publishing Company, Advanced Book Program.

Lomax, H. and Casey, N. (1998). Recording social life: Reflexivity and video methodology. Social Research Online, 3(2). [online]. Available from: http://www.socresonline.org.uk/3/2/1.html.

Losse, A., Henderson, S. E., Elliman, D., Hall, D., Knight, E. and Jongmans, M. (1991). Clumsiness in children-do they grow out of it? A 10-year follow-up study. Developmental Medicine & Child Neurology, 33(1), pp.55–68.

Lou, S.J., Shih, R. C., Tseng, K. H., Diez, C. R. and Tsai, H. Y. (2010). How to promote knowledge transfer through a problem-based learning Internet platform for vocational high school students. European Journal of Engineering Education, 35(5), pp.539–551.

De Luca, V.W. (1992). Survey of Technology Education Problem-Solving Activities. Technology Teacher, 51, p.n5.

Lynch, M. (2000). Against reflexivity as an academic virtue and source of privileged knowledge. Theory, Culture & Society, 17(3), pp.26–54.

Macphail, A. (2001). Nominal Group Technique: a useful method for working with young people. British Educational Research Journal, 27(2), pp.161–170.

Martinez, M.E. (2000). Education as the Cultivation of Intelligence. Lawrence Erlbaum.

Marzano, R.J., Brandt, R.S., Hughes, C.S., Jones, B.F., Pressiesen, B.Z., Rankin, S.C., & Suhor, C. (1988). *Dimensions of thinking: A framework for curriculum and instruction.* Alexandria, VA: Association for Supervision and Curriculum Development.

Marzano, R.J. and Kendall, J.S. (2007). The new taxonomy of educational objectives. Corwin Pr.

Mauthner, N.S. and Doucet, A. (2003). Reflexive accounts and accounts of reflexivity in qualitative data analysis. Sociology, 37(3), pp.413–431.

Mawson, B. (2003). BeyondThe Design Process': An alternative pedagogy for technology education. International Journal of Technology and Design Education, 13(2), pp.117–128.

Maxwell, J.A. (1992). Understanding and validity in qualitative research. Harvard educational review, 62(3), pp.279–301.

Maybin, J. (2004). Children's voices: Talk, knowledge and identity. In D. Graddol, J. Maybin, & B. S. Stierer, eds. Researching language and literacy in social context. Clevedon: Multilingual Matters, pp. 131–150.

Mayer, R.E. (1992). Thinking, problem solving, cognition . WH Freeman/Times Books/Henry Holt & Co.

Mayring, P. (2000). Qualitative content analysis. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research.

McCade, J. (1990). Problem solving: Much more than just design. Journal of Technology Education, 2(1).

McCallin, A. M. (2003). Grappling with the literature in a grounded theory study. Contemporary Nurse, 15(12), 6169.

McCormick, R. (2004). Issues of learning and knowledge in technology education. International Journal of Technology and Design Education, 14(1), pp.21–44.

McCormick, R., Murphy, P. and Hennessy, S. (1994). Problem-solving processes in technology education: A pilot study. International Journal of Technology and Design Education, 4(1), pp.5–34.

McCormick, R. (1996) Theoretical and empirical issues for technology education research. Proceedings of the First AAAS Technology Education Research Conference. Project 2061.

McLellan, R. and Nicholl, B. (2011). 'If I was going to design a chair, the last thing I would look at is a chair': product analysis and the causes of fixation in students' design work 11–16 years. International Journal of Technology and Design Education, 21(1), pp.71–92.

Medway, P. (1992). Constructions of technology: reflections on a new subject. Technological literacy and the curriculum, p.65.

Meetoo, D. and Temple, B. (2003). Issues in multi-method research: constructing self-care. International Journal of Qualitative Methods, 2(3), pp.1–21.

Meichtry, Y.J. (1999). The nature of science and scientific knowledge: Implications for a pre-service elementary methods course. Science & Education, 8(3), pp.273–286.

Mercer, N. (1996). The quality of talk in children's collaborative activity in the classroom. Learning and instruction, 6(4), pp.359–377.

Miles, M. B. & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook. Sage Publications Incorporated.

Miller, G.A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychological review, 63(2), p.81.

Miller, G.A., Galanter, E. and Pribram, K.H. (1960). The unit of analysis.

Mioduser, D. (2002). Evaluation/modification cycles in junior high students' technological problem solving. International Journal of Technology and Design Education, 12(2), pp.123–138.

Moghaddam, A. (2006). Coding Issues in Grounded Theory. Isuues in Educational Research, 16(1). Sage. pp.52-66.

Moore, D.S. (1982). Reconsidering Bloom's taxonomy of educational objectives, cognitive domain. Educational Theory, 32(1), pp.29–34.

Moran, S. and John-Steiner, V. (1993). Creativity in the making: Vygotsky's contemporary contribution to the dialectic of development and creativity. In Creativity and development. Oxford: Oxford University Press, pp. 61–90.

Moran, S., John-Steiner, V. and Sawyer, R. (2003). Creativity in the Making. Creativity and development, pp.61–90.

Morgan, K. (2008). Does Polanyi's Tacit Knowledge Dimension Exist? In Polanyi Society Conference at Loyola University, Chicago, IL in June.

Necka, E. (2003). Creative interaction: A conceptual schema for the process of producing ideas and judging the outcomes. In Critical creative processes. Cresskill, NJ: Hampton Press.

Newell, A. and Simon, H. (1972). Human Problem Solving. Englewood Cliffs, New Jersey: Prentice-Hall.

Niaz, M. (1995). Cognitive conflict as a teaching strategy in solving chemistry problems: A dialectic–constructivist perspective. Journal of Research in Science Teaching, 32(9), pp.959–970.

Niekerk, E., Ankiewicz, P. and Swardt, E. (2008). A process-based assessment framework for technology education: a case study. International Journal of Technology and Design Education, 20(2), pp.191–215.

Norman, E. and Roberts, P. (1992). The Nature of Learning and Progression in Design and Technology. In IDATER 92. The International Conference on Design and Technology Educational Research and Curriculum Development. Loughborough: Loughborough University, pp. 9–14.

Nurmi, H. (1985). Some properties of the Lehrer-Wagner method for reaching rational consensus. Synthese, 62(1), pp.13–24.

Olson, H. (1995). Quantitative' versus' qualitative research: The wrong question. Retrieved March, 5, p.2003.

Ormrod, J.E. (2008). Human Learning. Upper Saddle River, NJ: Merrill/Prentice Hall.

Overskeid, G. (1995). Cognitivist or behaviourist-Who can tell the difference? The case of implicit and explicit knowledge. British Journal of Psychology, 86(4), pp.517–522.

Perkins, D.N. and Salomon, G. (1988). Teaching for Transfer. Educational Leadership, 46(1), pp.22–32.

Peterson, R.E. (2002). Establishing the creative environment in technology education: Creativity doesn't just happen by chance; the prepared environment nourished it. Journal article by Richard E. Peterson; The Technology Teacher, 61.

Petrina, S. (2000). The politics of technological literacy. International Journal of Technology and Design Education, 10(2), pp.181–206.

Ploetzner, R., Fehse, E., Hermann, F. and Kneser, C. (1997). Modeling the knowledge-based exchange of information during collaborative problem solving on the basis of deductive self-diagnosis. In Proceedings of the eighth world conference on artificial intelligence in education. pp. 223–230.

Polanyi, M. (1967). The tacit dimension London. Routledge and Kegan Paul.

Qin, Z., Johnson, D.W. and Johnson, R.T. (1995). Cooperative versus competitive efforts and problem solving. Review of Educational Research, 65(2), pp.129–143.

Raab, S.S, Stone, C. H., Wojcik, E. M., Geisinger, K. R., Dahmoush, L. Garcia, F. U., Grzybicki, D. M., Jonosky, J. E., Meierm F. A. and Zarbo, R. J. (2006). Use of a new method in reaching consensus on the cause of cytologic-histologic correlation discrepancy. American journal of clinical pathology, 126(6), pp.836–842.

Rapp, F. (1999). The material and cultural aspects of technology. Society for Philosophy and Technology, 4(3). Digital Library and Archives of the Virginia Tech University Libraries.

Regehr, G. and Norman, G.R. (1996). Issues in cognitive psychology: implications for professional education. Academic medicine: journal of the Association of American Medical Colleges, 71(9), p.988.

Ritz, J. M., Deal, W. F., Hadley, F., Jacobs, J. A., Kildruff, T. F., and Skena, K. G. (1986). Problem Solving. The Technology Teacher, 46(2), pp.15–22.

Roden, C. (1997). Young children's problem-solving in design and technology: towards a taxonomy of strategies. Journal of Design & Technology Education, 2(1).

Roozenburg, N. F. M. and Eekels, J. (1995). Product design: fundamentals and methods. Wiley Chichester.

Ropohl, G. (1997). Knowledge types in technology. International Journal of Technology and Design Education, 7(1), pp.65–72.

Roschelle, J. and Teasley, S.D. (1994). The construction of shared knowledge in collaborative problem solving. NATO ASI Series F Computer and Systems Sciences, 128, pp.69–69.

Rowe, G. and Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. International journal of forecasting, 15(4), pp.353–375.

Rowell, P.M. (2002). Peer interactions in shared technological activity: A study of participation. International Journal of Technology and Design Education, 12(1), pp.1–22.

Rule, A.C. and Stewart, R.A. (2002). Effects of practical life materials on kindergartners' fine motor skills. Early Childhood Education Journal, 30(1), pp.9–13.

Rumelhart, D. and Norman, D. (1978). Accretion, tuning and restructuring: three modes of learning. In J. W. Cotton & R. Klatzky, eds. Semantic Factors in Cognition. Hillsdale, NJ.: Erlbaum.

Runco, M.A. (2007). Creativity: Theories and themes: Research, development, and practice. Academic Press.

Runco, M.A. and Chand, I. (1995). Cognition and creativity. Educational psychology review, 7(3), pp.243–267.

Rutland, M. and Barlex, David. (2007). Perspectives on pupil creativity in design and technology in the lower secondary curriculum in England. International Journal of Technology and Design Education, 18(2), pp.139–165.

Salamatov, Y. et al. (1999). TRIZ: the right solution at the right time: a guide to innovative problem solving. Insytec.

Salomon, G. (2010). It's not just the tool, but the educational rationale that counts. In Keynote Address. Ed-Media 2000. Montreal, Quebec, Canada: Association for the Advancement of Computing in Education. [online]. Available from: http://www.aace.org/conf/edmedia/00/salomonkeynote.htm.

Salomon, G. and Globerson, T. (1989). When teams do not function the way they ought to. International journal of Educational research, 13(1), pp.89–99.

SCCC. (1996). Technology Education in Scottish Schools: A Statement of Position.
Schaafstal, A., Schraagen, J.M. and van Berl, M. (2000). Cognitive task analysis and innovation of training: The case of structured troubleshooting. Human Factors: The Journal of the Human Factors and Ergonomics Society, 42(1), pp.75–86.

Schell, J.W. and Black, R.S. (1997). Situation Learning: An Inductive Case Study of a Collaborative Learning Experience.

Schon, D. (1983). The reflective practitioner: how professionals think in action. London: Temple Smith.

Schraw, G., Dunkle, M.E. and Bendixen, L.D. (1995). Cognitive processes in well-defined and ill-defined problem solving. Applied Cognitive Psychology, 9(6), pp.523–538.

Schwandt, T.A. and others. (1994). Constructivist, interpretivist approaches to human inquiry. Handbook of qualitative research, 1, pp.118–37.

Scott, M. (2001). Tactual perception. Australasian Journal of Philosophy, 79(2), pp.149–160.

Scrivener, S.A.R., Liang, K. and Ball, L.J. (2002). Extending the Design Problem-Solving Process Model: Requirements and Outcomes.

Senesi, P.H. (1998). Technological knowledge, concepts and attitudes in nursery school.

Sherif, M. et al. (1961). Intergroup conflict and cooperation: The Robbers Cave experiment. University Book Exchange Norman, OK.

Simon, H.A. and Newell, A. (1971). Human problem solving: The state of the theory in 1970. American Psychologist; American Psychologist, 26(2), p.145.

Simon, H.A. and Simon, P.A. (1962). Trial and error search in solving difficult problems: Evidence from the game of chess. Behavioral Science, 7(4), pp.425–429.

Skinner, B. (1966). An operant analysis of problem solving. Problem solving: Research, method and theory, pp.225–257.

Skinner, B.F. (1984). An operant analysis of problem solving. Problem solving: Research, method and theory, pp.225–257.

Skinner, B.F. (1953). Science and human behavior. New York: Macmillan.

Sober, E. (1993). Epistemology for empiricists. Midwest studies in philosophy, 18(1), pp.39–61.

Spearman, C. (1904). ' General Intelligence,' Objectively Determined and Measured. The American Journal of Psychology, 15(2), pp.201–292.

Spendlove, D. (2007). The locating of emotion within a creative, learning and product orientated design and technology experience: person, process, product. International Journal of Technology and Design Education, 18(1), pp.45–57.

SQA (2011). Higher Technological Studies, Arrangements (4th Ed). Scottish Qualifications Authority. [on line] Available from: http://www.sqa.org.uk/sqa/files_ccc/Technological_Studies_Higher.pdf

Sternberg, R. J. (1980). Sketch of a componential subtheory of human intelligence. Behavioural and brain sciences, 3(4) Cambridge University Press. pp573-583.

Sternberg, R. J. (1984). Beyond IQ: a triarchic theory of human intelligence. Cambridge University Press.

Sternberg, R. J. (1999). The theory of successful intelligence. Review of general psychology, 3(4) Educational Publishing Foundation. pp.292-316.

Sternberg, R.J. (2006). Creating a vision of creativity: The first 25 years. Psychology of Aesthetics, Creativity, and the Arts; Psychology of Aesthetics, Creativity, and the Arts, (1), p.2.

Stevenson, J. (2004). Developing technological knowledge. International Journal of Technology and Design Education, 14(1), pp.5–19.

Strauss, A. & Corbin, J. (1994) in Denzine, N. K. and Lincoln, Y. S. (Eds) Handbook of qualitative research. England, Sage Publications. pp.237-285.

Sveiby, K.E. (1997). The new organizational wealth: Managing and measuring knowledge-based assets. Berrett-Koehler Publishers.

Taber, K.S. (2001). The mismatch between assumed prior knowledge and the learner's conceptions: a typology of learning impediments. Educational Studies, 27(2), pp.159–171.

Teddlie, C. and Tashakkori, A. (2006). A general typology of research designs featuring mixed methods. Research in the Schools, 13(1), pp.12–28.

Treffinger, D.J. and Isaksen, S. (1987). Research on creativity assessment. Frontiers of creativity research: Beyond the basics, pp.103–119.

Twyford, J. and Järvinen, E.M. (2000). The formation of children's technological concepts: A study of what it means to do technology from a child's perspective.
Vincenti, W.G. (1990). What engineers know and how they know it: Analytical studies from aeronautical history.

De Vries, M. (1996). Technology Education: Beyond the 'Technology is Applied Science' Paradigm. [online]. Available from: http://scholar.lib.vt.edu/ejournals/JTE/v8n1/deVries.html [Accessed July 20, 2012].

Waetjen, W. (1993). Technological problem solving. Reston, VA: International Technological Education Society.

Waetjen, W.B. (1993). Technological literacy reconsidered. Journal of Technology Education, 4(2).

Webb, N.M. (1989). Peer interaction and learning in small groups. International journal of Educational research, 13(1), pp.21–39.

Webb, N.M. (1984). Stability of small group interaction and achievement over time. Journal of Educational Psychology, 76(2), p.211.

Webb, N.M. and Cullian, L.K. (1983). Group interaction and achievement in small groups: Stability over time. American Educational Research Journal, 20(3), pp.411–423.

Welch, M. (1999). Analyzing the tacit strategies of novice designers. Research in Science & Technological Education, 17(1), pp.19–34.

Welch, M., Barlex, D. and Lim, H.S. (2000). Sketching: Friend or Foe to the Novice Designer? International Journal of Technology and Design Education, 10(2), pp.125–148.

Welch, M. and Lim, H.S. (1998). The effect of problem type on the strategies used by novice designers.

Welch, M. and Lim, H.S. (2000). The strategic thinking of novice designers: Discontinuity between theory and practice.

Whyte, J. (1984). Observing sex stereotypes and interactions in the school lab and workshop. Educational Review, 36(1), pp.75–86.

Williams, A., Ostwald, M. and Askland, H.H. (2010). The design studio, models of creativity and the education of future designers. In Proceedings of the 1st DESIRE Network Conference on Creativity and Innovation in Design. pp. 131–137.

Williams, J. (2002). Processes of Science and Technology: A Rationale for Cooperation or Separation. In Technology Education in the Curriculum: Relationships With Other Subjects. Papers PATT-12 Conference March. pp. 33–50.

Williams, P.J. (2000). Design: The Only Methodology of Technology? Journal of Technology Education, 11(2).

Wilson, V. and Harris, M. (2004). Creating change? A review of the impact of design and technology in schools in England. Journal of Technology Education, 15(2).

Winkler, K. P. (Ed) (1996). John Locke: An essay concerning human understanding, Hackett Publishing Company, Indianapolis, IN.

Wohldmann, E.L. and Healy, A.F. (2006). Exploring specificity of speeded aiming movements: Examining different measures of transfer. Memory & cognition, 38(3), pp.344–355.

Wong, Y.L. and Siu, K.W.M. (2011). A model of creative design process for fostering creativity of students in design education. International Journal of Technology and Design Education. [online]. Available from: http://www.springerlink.com/index/10.1007/s10798-011-9162-8.

Xu, Z. (2009). An automatic approach to reaching consensus in multiple attribute group decision making. Computers & Industrial Engineering, 56(4), pp.1369–1374.

Zuga, K.F. (1986). Evolving Theory of Curriculum in Industrial Education. Journal of Industrial Teacher Education, 23(3).

Zuga, K.F. (1994). Implementing Technology Education: A Review and Synthesis of the Research Literature. Information Series No. 356.