An Investigation of the Integration of Science, Mathematics and Technology within a Technological Design Context

A thesis

submitted in fulfilment

of the requirements for the degree

of

Doctor of Philosophy in [Faculty of Education]

at

The University of Waikato

by

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THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2017

ABSTRACT

This research focused on studying the integration of science, mathematics and technology in a technological design context. The daily classroom practices of a teacher and 19 of his students (aged 15-16) in a technology class were analysed with a focus on the knowledge and skills used while designing individualised projects (street luge gravity-powered vehicle) with a view to identifying the integration of cross-disciplinary knowledge. This research is aligned with the elements of both interpretive and critical theory paradigms. The focus of the interpretive paradigm rests on how students construct meaning from their personal experiences and their world view. Critical theory is used to create a platform for integration by understanding the current practices and phenomena in a technology classroom to develop strategies that could be implemented in other classrooms to create an integrative learning environment.

This research provided an insight into the teachers' and students' perceptions of integration and the categorisation of the knowledge (science, mathematics and technology) they bring to technology classroom. The four school terms (approx. 10 weeks each) of the year provided the time periods for the aspects of the project: design in Term 1, construction in Term 2 and Term 3, and testing and evaluation in Term 4. Analysis of the classroom observations, student questionnaires, student portfolios and teacher interviews was used to investigate how students integrate science, mathematics and technology.

The teacher's aim was to develop and foster technological capability by encouraging technology-based approaches, and the students wanted to design and make a technological product. The teacher presented to, discussed with and helped students to appropriate technological applications with a perspective on acquiring technological knowledge. While mathematics and science content was applied to the project, it was not the goal of the teacher to teach these concepts; they were used as a means to the end of designing a project. Technology was the environment in which science and mathematics was applied when the teacher was required to provide a detailed explanation of the physical phenomenon. The use of scientific terminology by the teacher was prominent during technological activities which led to the social acceptance of the terms and their meaning. Students got involved in the design and making of a technological product and, in the process, understood some basic principles from science which governed the functionality of product components. The understanding of principles from science and mathematics assisted students in making informed decisions while developing technological outcomes. Allowing students to argue for their explanations using science and mathematics strengthened those explanations. It may not be an absolute necessity to know the principles of science governing the design but evidence shows that such an understanding is developed by the students during the course of the design and construction of the product.

This study concludes that when teachers assist students with developing their understanding of a technological product through the design process, the students naturally integrate science, mathematics and technology. This study also indicates that many students could explicitly refer to the technological

knowledge gained through participation in the community of practice and could distinguish the applied components of science and mathematics. The experience of developing a functional product encouraged the use and application of scientific concepts and terminology by the students. The research findings, therefore, present a case for technology teachers and STEM educators to place an emphasis within their teaching programmes on designing and making to enhance student conceptual understanding from science and mathematics through technological modelling.

ACKNOWLEDGEMENTS

Many people have kindly contributed time, expertise and support during my research. I would like to especially thank the following people, and share the achievement of this thesis with them.

My chief supervisor, Professor P. John Williams for his unwavering support and the critical feedback that has helped shape my thesis. I thank you for providing me with adequate support when I really needed it. You saw value in my proposal and agreed to work with me till the completion of my thesis. Thank you very much. You have made a significant contribution, not only to this thesis but also, to my life.

The student research participants and the technology teachers, who generously gave their time and support to me, that enabled this research to be undertaken.

My Father and Mother, whose untiring patience, financial support and encouragement have been ever present and much appreciated. Their understanding, support, encouragement of and commitment to my education made my future and I am proud of you my dad and mom. God bless you.

My colleagues, in technology education, who have encouraged and supported me to undertake this research. I would also like to offer my gratitude to my Manager Gerhard for his support, encouragement and understanding expressed during my PhD.

And finally, I could not have undertaken such a journey without the unfailing love and support of my wife Blessy T. Thomas. Your love, support, encouragement, commitment to our family, was my passion during writing of the final chapters. I say thank you very much and God bless you.

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 Technology Education

Technology Education is a learning area that deals with the ways people develop their technological environment to better suit their needs (de Vries, 2009). The world today is technological; people engage with, and use technology from the minute they are born, some even before. According to Dreyer and van den Heever (1994), technology is the application of knowledge and skills through the use of resources to solve problems and produce products. It is found in all aspects of life today, from the home to highly complex industries.

One of the primary qualities of human activity is change. Due to their limited physical capabilities, humans rely on technology to meet challenges in their environment. Technology has been defined as a practical activity with its goal being to solve a problem through the application of knowledge, which includes scientific and other kinds of knowledge (Naughton, 1996). The practical activity can initiate integration of knowledge from science, mathematics and technology to satisfy human needs or solve problems. Human problem solving is highly complex in nature and can be broken down into identifiable processes in order to study the integration of knowledge from science, mathematics and technology.

A consideration of the nature of technology indicates that technological knowledge and practices are socially constructed and context dependent and are situated within their historical, cultural and institutional setting (Wertsch, 1991). Technology is an activity that involves not only the social, but also the physical context, with thinking and language being structured by the objects and tools of action. Technology education explicitly deals with the technological processes of investigating, designing, making and appraising technological solutions for identified problems or recognised opportunities within a social and cultural context.

Technology programmes in schools using authentic learning offer numerous opportunities for facilitating the integration of curriculum areas. Compton and France (2007) recognise that technology is increasingly interdisciplinary and requires technologists to work in an integrated manner. Fleer and Jane (1999) suggest that it has a symbiotic relationship with a number of other curriculum areas meaning that, through technology, students will deploy knowledge from a range of other disciplines in meaningful contexts, thus enhancing understanding of technology and other curriculum areas.

Little attention has been paid to studying the integration of cross-disciplinary knowledge in technology: the practices of justifying negotiations based on scientific, mathematical or technological concepts, arguing for selection among alternative acceptable solutions (see Johnston, Lee & McGregor, 2002). A design context in a technology classroom has the potential to incorporate science and mathematics in defining a problem to be worked on to generate possible and feasible solutions. The process of arriving at a solution involves investigations and practical application of knowledge, skills, tools and materials.

The concept of curriculum integration is complex and challenging, as integration of subjects is more than a matter of simply putting different subject areas together. Real world problems are not separated into isolated disciplines, but they bring knowledge from various subjects and disciplines together ((Beane, 1995; Czerniak et al., 1999; Jacobs, 1989). In today's world, people need set of skills that cut across the disciplines and can recall knowledge as and when required or have to be prepared to learn new information to be applied as usable knowledge. However, researchers and educators have not come to a consensus around a clear definition and conceptualization of curriculum integration (Czerniak et al., 1999; Huntley, 1998). The meaning of the term 'Integration' remains vague.

The terms ''multidisciplinary'' and ''interdisciplinary are most frequently used in the literature to explain integration. Lederman and Niess (1997) used the metaphor of chicken noodle soup versus tomato soup to explain the differences between multidisciplinary and interdisciplinary approaches. Their description of multidisciplinary integration is characterised where each ingredient (new information) maintains its identity without a direct mixture, but they yet come together to make a new body of knowledge. Their description of interdisciplinary integration was a contrast to multidisciplinary approach in the sense that the boundaries among the subjects are blurry, but the approach begins and ends with the skills and contents of various subjects (Beane, 1997; Bellack & Kliebard, 1971), and students are expected to make the links with the different subjects taught in different classrooms. The interdisciplinary approach begins with a theme, problem or an issue that brings in the content and skills in multiple disciplinary subjects (Beane, 1997; Bellack & Kliebard, 1971). An interdisciplinary approach cuts across different subject areas rather than subject based content and skills (Drake, 1991; 1998; Jacobs, 1989). Many researchers suggest than an interdisciplinary approach is the best form of integration subjects (Beane, 1997; Bellack & Kliebard, 1971). This study considers the approach taken by the teacher to be interdisciplinary in nature where the need and interest of the students (real world problem) were the starting point of the project. This study also veiw the 'use' of information from science to explain physical phenomenon and the 'integration' of mathematics and science as the application of information to improve or modify the functionality of a teachnological product.

Beane (1997) pointed out that curriculum integration involved four major aspects: the integration of experience, the social integration, the integration of knowledge, and the integration as a curriculum design. The *integration of experience* suggests that learning involves integrating past experiences to make meaning of new experiences, or replace existing knowledge. The teacher recalled past knowledge and experience of the students in technology. *Social integration* was also observed in the workshop whereby students collaborated and shared knowledge and experience to make learning more accessible and meaningful. The *integration of knowledge* where knowledge was constructed by students through active thinking in confronting issues and solving problems during design and construction stages. This led to the integration of science and mathematics in the design context. The *integration as a curriculum design* was implemented through the third strand in the New Zealand 2007 technology curriculum namely the *Nature of Technology* by designing problems and issues that are of personal and social significance in the real world. In conclusion, the New Zealand technology curriculum provides a framework for integrating meaningful content in real life problem solving settings. It can be said that the technological design context was grounded in the tenets of social constructivism.

This research is a direct result of several need statements and proposals published in the field of both STEM and technology education, and it is a testing of key recommendations made by national organizations (Department of Education & Skills, 2006; AAAS, 1989, 1993; ABET, 2004; ITEA, 1996, 2000; NCTM 1989, 2000; NRC, 1994) representing the fields of STEM. A number of governments have recognised the significance of the STEM areas as an important step towards economic development. These recommendations called for more emphasis on technology, science, and mathematics, and for further research on the effective delivery of the STEM areas in an integrated fashion.

My education and engineering background, in addition to professional development and other experiences contributed to my choice for this qualitative research study. As a teacher and a STEM associate in the past, I have had considerable contact with children from a range of schools and regularly interacted with science and mathematics teachers about concepts and knowledge and effective ways of teaching. I was invited to observe and help deliver STEM sessions across school districts in Greater Manchester and West Yorkshire in England. These STEM sessions were aimed at designing and making products in a short span of time and teaching specific science and mathematics content. I appreciated the curiosity and interest of the students when they got involved in practical activities. I wondered why the UK government did not view a school subject like Design and Technology and ignored its nature of naturally integrating science and mathematics with technology through the design process. The Science and Mathematics teachers acknowledged the significance of a subject like Design and Technology in the school curriculum, but had little knowledge about how to use their school subjects in a real life context as a vehicle to integrate knowledge from science and mathematics. I also became aware of the need to enhance the knowledge and expertise in the area of technology education, especially its potential to naturally integrate science and mathematics. This is one of the incidents, which involved conversations with school teachers and students, triggered the motivation for this study as it left me wondering about teachers (science, mathematics and technology) and the level of awareness for integration a future doctoral study could provide to facilitate STEM and its effective implementation.

Reflecting on my knowledge and experience of technology education, I realised how misinformed I was in my conversations about the true potential of technology as a school subject. From my perspective, design and technology should be provided equal status to other established school subjects such as science and mathematics. I am keen to explore the opportunities to effectively utilise technology education and the authentic contexts it affords to integrate science, mathematics and technology and to inculcate technological literacy amongst the students.

1.2 Context of this Study

This research is a study of the daily classroom practices of a teacher and 19 of his students (age 15-16) in a Year 11 technology class which had a major focus on the knowledge and skills needed to design and make a gravity-powered luge, with a view to identifying possible ways of integrating cross-disciplinary knowledge. This research has been aligned with the elements of both an interpretive and critical theory paradigm and will adopt a case study methodology. The focus of the interpretive paradigm rests on how students construct meaning from their personal experiences and their world view. Critical theory is used to create a platform for integration by understanding the current practices and phenomena in a technology classroom to develop effective strategies that could be implemented in other classrooms to create an integrative learning environment.

The four school terms (approximately 10 weeks each) of the year provided the general time periods for the aspects of the project: design in Term 1, construction in Term 2 and Term 3, and evaluation in Term 4, though there was overlap. The classroom observations were conducted four times a week (4 hours each week) over a period of 10 months at a local high school with Year 11 students. Analysis of the classroom observations, student questionnaires, student portfolios and teacher interviews was used to investigate how students integrate science, mathematics and technology while designing in technology.

1.3 Aim of the Research

Students often find it difficult to transfer knowledge they have acquired from the classrooms to real world problems. This may be attributable to the practice of teachers who move from topic to topic without making the logical connections explicit (Wineburg & Grossman, 2000).

A possible solution to develop curricular connections lies in fostering an integrated learning environment which supports the use of knowledge and skills from several areas (Doppelt, Mehalik & Schunn, 2005). The aim of this research is to better understand the design and delivery of integrated STEM instruction through technology. Integrated instruction has been defined as a strategic approach that integrates knowledge from various disciplines (Jacobs, 1989) so that learning becomes relevant for the learners.

This research explores the nature of technology in a secondary classroom with a focus on the integration of science and mathematics. This study will further provide recommendations and implications for teaching in a technology classroom to support an integrated learning environment. An integrated learning environment is more than the individual study of mathematics and science but is the effective utilisation of the procedural knowledge in technology and the integration of conceptual content knowledge from science or mathematics within the context of technology as or when required; it can be an interdisciplinary study of science, mathematics and technology in the form of designing and making.

1.3.1 Main Research Questions

The main research questions with sub-research questions are:

1. How does a technological design context of designing and making a product influence the thinking and practices of the teacher and the students in terms of integration?
    a) how the nature of technology best engages students in a meaningful learning environment by developing technological knowledge with integrated elements of science and mathematics?
    b) how the teacher taught and students learnt in technology?

2. How did the teacher and the students acknowledge their own thinking with regards to the transfer of science and maths knowledge to technology?

a) how the integration of science, mathematics and technology appears to occur in the classroom where the intent of the teacher and the students was to develop a technological product?
b) the aspect of the learning environment which shapes the thinking of the teacher and students leading to the development of a co-constructed version of knowledge?

1.4 Overview of Chapters

This thesis is organised into eight chapters outlined below.

Chapter 1 – Introduction

This introduces a brief overview of the study and the various sections of the thesis document.

Chapter 2 - Literature Review

There are four aspects to the literature review. The first investigates literature relevant to technology with its definition, history, nature and development; the second considers technology education and its relationship with the broader context of technology. The aims and objectives of technology education are explored in both the New Zealand and international context. Thirdly the domain of knowledge specific to technology is explored; fourthly technology as a learning environment is explored with a special interest in the integration of knowledge from science and mathematics in a technological design context. Further the literature review considers the constructivist views and sociocultural learning theory, the learning theories underpinning this study with a focus on a technology classroom. This final section draws together technology education and the theories of learning. This chapter concludes with an outline of the significance and rationale of the study.

Chapter 3 - Research Methodology and Methods

This chapter discusses the various research paradigms and justifies the paradigm adopted for this study. This chapter further outlines the background, design, role of the researcher, methods and process used for data analysis and identification of themes. This chapter concludes with the framework identified and used in the following findings and discussion chapters.

Chapters 4, 5 and 6 - Findings

These chapters use the developed framework to investigate the integration of science, mathematics and technology during a technology project undertaken by Years 11 students from a High School in Hamilton. The data in this study is presented in a narrative fashion divided into Stages 1, 2 and 3. The stages report the practices and perceptions of the students from the beginning of the project (Term 1) till its completion (Term 4). The nature of technology and the integration of science, mathematics and technology while undertaking a design project are presented. There are three distinct chapters, one for each stage of designing, construction and testing of the product.

Chapter 7 - Discussion

This is the chapter in which the results and literature are synthesised to develop understanding about the integration of science, mathematics and technology in a secondary context. This chapter is organised around the research questions.

Chapter 8 - Conclusions

This chapter presents the conclusions of the study findings with implications for technology teachers, STEM educators and researchers with potential future areas of study identified. The research questions have also been answered explicitly in this chapter.

1.5 Conclusion

This chapter has introduced this study by a brief overview. It also outlines the context and methodology used to frame the study. It has briefly discussed the rationale for the study and given a brief outline of the contents of each chapter. The next chapter, Chapter 2 gives a detailed review of relevant literature in the study and outlines the research questions.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview of Chapter

In the first section (Section 1.1 Technology Education), the literature has been organised around the various features of technology in general as they apply to this research. The meaning of technology has been researched as perceived by various authors and educational agencies. The purpose of this section is thus to present aspects of technology and its relationship with technology education. In the following sections, various perspectives of technology will be discussed with notions of knowledge in technology education. The rationale for technology education in schools has been discussed. The relationship between science and technology, seemingly the starting point for many discussions on technological knowledge, is also addressed.

This review of literature will show that there are advantages to creating an integrative learning environment which connects the learning in other subject areas to technology and that more research is needed. This perspective of creating an integrative learning environment through technology has implications for STEM education and the implementation of an integrative learning environment and has been discussed in the second section of this chapter. The final section of this chapter highlights learning in technology, including social constructivist learning, in order to inform how we might draw on and use knowledge and it includes a discussion of the transfer of knowledge. The remainder of this section explores how these perspectives provide different views on knowledge from a social perspective. A combination and adaptation of elements of these perspectives provides the conceptual framework for this study, as discussed towards the end of the chapter.

The chapter concludes with a summary of the literature review which positions the research to be undertaken and from which the aim and specific objectives are derived and presented.

2.2 Introduction

About 2.4 million years ago, humans (as we would call them now) created primitive tools for food and shelter by chipping away the edges of stones. Tool making was the first technology and was seen as a means to solve problems. Over the millennia, humans have refined their capability to create technological ways to solve problems. Technology is created, managed and used by societies and individuals, according to their goals and values (ITEA, 2000). Technology has the potential to improve or damage the human situation, to save or destroy lives. The promise of the future lies not in technology, but in people's ability to use it, manage, assess and understand it. The major goal of technology education is then to develop a technologically literate citizenry, who will have the ability to use, manage, assess and understand technology.

Technological, scientific and mathematical literacy go hand in hand. Designers and technologists use mathematics and science, scientists use maths and technology, and mathematicians use science and technology. Scientists use methods of inquiry when observing the natural world and building explanatory structures. Technologists design products and systems to create the human-made world. Just as mathematics and science consider problem solving a foundational skill, technology educators include the idea of design and inductive/deductive problem-solving as an essential component of technology. Incorporation of these essential components can move the society towards a technologically literate society which will help make wise decisions for the benefit of the society (Pearson & Young, 2002).

The following section defines the meaning of technology as derived from the literature.

2.3 Technology and Technology Education

The coming sections will discuss different ways technology can be defined and how the framework of a discipline can be used in the context of technology. The perspectives on technology education will be identified and the discussion will develop an understanding of the meaning of technological knowledge and its significance within the framework of a discipline in the school context.

2.3.1 What is Technology?

The concept of technology has varying interpretations. Technology has been equated with machinery such as computers, phones, cars, etc. (Naughton, 1986). Technology has also been defined as a creative, purposeful activity aimed at meeting needs and opportunities through the development of products, systems or the environment (Black, 1998). Black emphasises that knowledge, skills and resources are combined in technology to help solve practical problems. Technological practice takes place within, and is influenced by, social context and interactions.

The question What is technology? is a central question that some philosophers of technology aim to answer. As the famous philosopher of science Marx Wartofsky commented:

> Technology is unfortunately too vague a term to define; or else, so broad in its scope that what it does define includes too much. For example, technology can be viewed as including all artifacts, that is, all things made by human beings. Since we 'make' language, literature, art, social organizations, beliefs, laws and theories as well as tools and machines, and their products, such an approach covers too much. (cited in Wartofsky, 1979, p. 177-178)

Some clarity of this term can be achieved by looking at various definitions. Many definitions of technology have been developed, a few of which are highlighted below.

Jacob Bigelow, an early author on technology, conceived of technology as a specific domain of knowledge: technology was “an account [...] of the principles, processes, and nomenclatures of the more conspicuous arts” (Bigelow, 1829, cited in Misa, 2009; Mitcham & Schatzberg, 2009). Ropohl (2009) defined "technology" as the "science of technics" (*Wissenschaft von der Technik*, where *Technik* denotes the domain of crafts and other areas of manufacturing, making, etc.). The important aspect of Bigelow's and Ropohl's definitions is that technology does not denote a domain of human activity (such as making or designing) or a domain of objects (technological innovations, such as solar panels), but a domain of knowledge.

Technology in the New Zealand Curriculum states that:

> Technology is a creative, purposeful activity aimed at meeting needs and opportunities through the development of products, systems or the environment. Knowledge, skills and resources are combined to help solve practical problems. Technological practice takes place within, and is influenced by, social context. (Ministry of Education, New Zealand, 2007, p. 6)

A review of a number of definitions of technology (Li-Hua, 2009) shows that there is quite an overlap among the various definitions found in the literature. Many definitions conceive of technology in Bigelow's and Ropohl's sense as a particular body of knowledge (thus making the philosophy of technology a branch of epistemology), but Bigelow and Ropohl do not agree on what kind of knowledge it is comprised. In some definitions it is seen as firm-specific knowledge about design and production processes, while others regard it as knowledge about natural phenomena and laws of nature that can be used to satisfy human needs and solve human problems (a view which closely resembles Francis Bacon's). Bacon (1620) did not distinguish between science and technology but saw technology as an integral part of natural philosophy and treated the carrying out of experiments and the construction of technological works on an equal footing.

Technology is defined as applied science by some (Maiztegui et al., 2002). According to Bunge (1996), technology should be understood as constituting a particular subdomain of the sciences, namely "applied science", as he called it. However, according to Aitken and Mills (1993), historical reflection disputes that concept of technology because the technologies of the wheel and axle, the bow, the boat and the melting of metals appeared many thousands years before the development of the discipline of science. Even the construction of Durham cathedral in the eleventh and twelfth centuries was a great technological achievement with no defined scientific knowledge base. Although a view of technology as being "just the totality of means for applying science" (Scharff, 2009) remains for some, most engineers and philosophers of technology agree that technology cannot be conceived of as the application of science in this sense. They contend that modern technology draws heavily on the discoveries of science, but there is still a fundamental difference between the two, namely their purpose and emphasis, which will be discussed in detail in subsequent sections.

2.3.2 History of Technological Thinking

Philosophers in Greek antiquity addressed questions related to the making of things. The terms "technique" and "technology" have their roots in the ancient Greek notion of "*techne*" (art, or craft-knowledge), that is, the body of knowledge associated with a particular practice of making (Parry, 2008). Originally, the term referred to a carpenter's craft-knowledge about how to make objects from wood (Fischer, 2004; Zoglauer, 2002), but later it was extended to include all sorts of craftsmanship, such as the ship's captain's *techne* of piloting a ship, the musician's *techne* of playing a particular kind of instrument, the farmer's *techne* of working the land, the statesman's *techne* of governing a state or *polis* or the physician's *techne* of healing patients (Nye, 2006; Parry, 2008).

Philosophers have been reflecting on technology-related matters since the beginning of Western philosophy. Those pre-nineteenth century philosophers who looked at aspects of technology did not do so with the aim of understanding technology as such. Rather, they examined technology in the context of more general philosophical projects aimed at clarifying traditional philosophical issues other than technology (Fischer, 1996). It is probably correct to conclude that before the mid to late nineteenth century, no philosopher considered himself as being a specialized philosopher of technology.

One reason for this is that before the mid to late nineteenth century, technology had not yet become the powerful and ubiquitously manifest phenomenon that it would later become. By the end of the nineteenth century, natural science in its present form had emerged from natural philosophy and technology had manifested itself as a phenomenon distinct from science. Accordingly, "until the twentieth century the phenomenon of technology remained a background phenomenon" (Ihde, 1991, p. 26) and the philosophy of technology "is primarily said to be a twentieth-century development" (Ihde, 2009, p. 55). Technology can be traced back to the very beginning when humans transformed the environment around them to fulfil their needs.

One reason for the emergence of the philosophy of technology in the twentieth century is the rapid development of technology at the time. According to the German philosopher Heidegger, not only did technology in the twentieth century develop more rapidly than in previous times and as a consequence became a more visible factor in everyday life, but, at the same time, the nature of technology itself underwent a profound change. The argument is found in a famous lecture that Heidegger gave in 1955, titled *The Question of Technology* (Heidegger, 1962), in which he inquired into the nature of technology.

Throughout the centuries, the ability to solve problems through design, production, appreciation, and appropriate use of technology, has improved the quality of human life. Quality of life is directly related to an ability to develop new technologies creatively while simultaneously appreciating scientific, economic, social and ecological considerations (Makgato, 1999). Thus, in the twentieth century, according to Heidegger, technology as a way of knowing assumed a new nature. In Heidegger's view, older technology imitated nature where entities and phenomenon already exist. While contemporary technology forces nature to deliver energy (or another kind of resource) whenever it is asked for and it therefore cannot be understood as objects made by man just to imitate nature. Nature to a large extent cannot produce things by itself but it could deliver resources in ways that man can purposefully utilise them to make man-made things. This study will not view a fundamental divide between older and contemporary technology and will take the position of nature as a source of resources to satisfy human needs.

2.3.3 Nature of Technology

As outlined earlier in this chapter, the purpose of technology is to intervene in the world in order to meet needs and realise opportunities. In this way it seeks to extend the made world in ways which will have planned and unplanned implications for what it is to be human. The purpose of technology could be understood by providing the nature and concept of technology within which it is embedded.

There has been much written in recent years relating to, and exploring, the diversity of concepts of technology. These have ranged from those dealing almost exclusively with exploring and frequently contesting, the nature of the relationship between technology and science (e.g., Allsop & Woolnough 1990; Ferna´ndez et al., 2002; Gardner 1994; Layton 1993), to those taking a wider more sociological perspective (e.g., Cockburn, 1993; Fischer, 2004; McCormick, Murphy & Hennessy, 1994; McGinn, 1990; Mitcham & Schatzberg, 2009; Wajcman, 1991). Due to historical and philosophical arguments by those such as Gardner (1994), the view of technology as a subset of science has largely been replaced with a view of science and technology as two autonomous and distinctive fields with close links. However, there are others - including many practicing technologists and scientists particularly in domains such as engineering - where the dominant knowledge base since the Renaissance period has tended to be science (Compton, 2004).

The nature of technology, however, is less well defined than the nature of science. As philosopher of science Marx Wartofsky noted, "technology” is unfortunately too vague a term to define a domain; or else, so broad in its scope that what it does define includes too much. For example, one may talk about technology as including all artefacts, that is, all things made by human beings. Since we make language, literature, art, social organizations, beliefs, laws and theories as well as “tools and machines, and their products, such an approach covers too much” (1979, p. 176). More clarity on this issue can be achieved by looking at the history of the term (e.g., Misa, 2009; Mitcham & Schatzberg, 2009; Nye, 2006) as well as at recent suggestions to define it.

Arthur (2009) takes a different starting point in considering the nature of technology and the way it evolves. He argues that technology can be seen as the exploitation of phenomena revealed by science. He rejects a simplistic ‘technology is applied science’ view but is adamant that it is from the discovery and understanding of phenomena that technologies spring. He notes that it should be clear that technologies cannot exist without phenomena. But the reverse is not true.

Phenomena purely in themselves may have nothing to do with technology. They simply exist in the world (the physical ones at least) and humans have no control over their form and existence, but to understand and use them where possible. Arthur (2009) notes that:

> Had our species been born into a universe with different phenomena we would have developed different technologies. And had we uncovered phenomena over historical times in a different sequence, we would have developed different technologies. (p. 66)

The concept of technology explored from a sociological perspective is often also based on a narrow, restrictive view of technology, albeit of yet a different kind (Compton, 2007). Knowledge is not narrow in terms of applied science or craft, but rather narrow by way of taking a materialistic or artefactual focus (Mather, 1995). Critical theorists like Cockburn (1993) and Rothschild (1982) provided a much needed and powerful critique of technology because of its ambiguous position, but this was somewhat limited to a critique of technological artefacts. More recent philosophers have addressed the missing links, however, with a reconceptualization of technology itself as situated human activity, reliant on and reflective of the social, cultural, political and environmental location (Barnett, 1995; Hansen, 1997; Lewis & Gagel, 1992; MacKenzie & Wajcman, 1985; Pacey, 1983).

The earlier attempts to define technology were oriented toward the nature of technology, or only some of the principal characteristics of technology (Zoglauer, 2002). Those definitions have not led to any generally accepted view of what technology is. In this context, historian of science and technology Thomas J. Misa (2009) observed that historians of technology have so far resisted defining "technology" in the same way that "no scholarly historian of art would feel the least temptation to define 'art', as if that complex nature of human creativity could be pinned down or defined by a few well-chosen words" (p. 8). The suggestion is that technology is far too complex and diverse a domain to define or to be able to talk about the nature of technology. Nordmann (2008) went even further by arguing that not only can the term technology not be defined, but also it should not be defined. According to Nordmann, it should be accepted that technology is too diverse a domain to be caught in a compact definition. Accordingly, instead of conceiving of technology as the name of a particular fixed collection of phenomena that can be investigated, Nordmann held that technology is best understood as what Grunwald and Julliard (2005) called a "reflective concept". According to the latter authors, technology should simply be taken to mean whatever is meant when the term is used. Using technology in this extremely loose manner can allow reflections on very different issues and phenomena to be connected and can serve as the core concept of the field of philosophy of technology.

Rather than asking what technology is, and how the nature of technology is to be characterized, it might be worth examining the nature of particular instances of technology and technological knowledge, and in doing so achieve more clarity about a number of local phenomena, one of which this study wishes to focus on: the integration of science, mathematics and technology.

There is a growing body of literature that considers technological knowledge to exist as distinct from, and fundamentally different to, other knowledge domains (e.g., Baird, 2002; Bybee, 2000; Custer, 1995; Layton, 1993; McCormick, 1997; McGinn, 1990; Staudenmaier, 1985). Technological knowledge includes understanding materials, resources and their part in enabling the success of a technological outcome. Technological knowledge also includes understanding the social and physical environment of any technological development. It includes knowledge of appropriate ethics, legal requirements, cultural or domain protocols, and personal/collective needs of the end-users and technologists specific to the development as well as the site where the outcome(s) of the development may be located (Ministry of Education, 2007).

As part of understanding the nature of technology, understanding the distinctiveness of its knowledge base is also important. The nature of technological knowledge rests on an understanding of its ontological and epistemological assumptions (Baird, 2002). Following on from a view of technology as a situated and purposeful activity embedded in the made world and impacted on by social, cultural, environmental, political and economic perspectives and contexts at both local and global levels, technology can be thought of as holding to an ontological process view of the world (de Vries, 2002; Ropohl, 1997). That is, what the world is made up of, and what it is to be human within that world, are mutually constitutive. In keeping with this, the knower and what is known and created in a material sense, are all interlinked (Cross, 2002).

The epistemology of technology, in keeping with sociocultural and constructivist theories, is socially constructed, its validation being usually located in a pragmatic theory of truth, where knowledge in any domain is validated by social agreement. However, as Baird (2002) discusses, the epistemic criteria for judgment of knowledge in the domain of technology should be materialist or referenced to the made rather than natural world as in the case of science or the imagined world as in the case of art and music.

This is not to say that the natural and imagined worlds are not important in technological endeavours. Technology constantly draws knowledge from other domains and operationalises this to solve problems. However, technological knowledge in this study gives both material and virtual primacy, acknowledging that "the things we make bear our knowledge of the world, on a par with the words we speak" (Baird, 2002, p. 1). Baird goes on further to argue the need for an epistemological shift by explaining that other domains (science and mathematics for example) may hold to a "justified true belief" or similarly propositional criteria for validating knowledge, whereas in technology this should be replaced by an intertwining of a "materials sense of truth with the notion of function" (p. 4). Knowledge therefore, within the domain of technology, is validated in relation to the successful function of the product or artefact.

The implications of this epistemological shift require a reconceptualization of the "key features" of knowledge such as "detachment, efficacy, longevity, connection and objectivity". (Baird, 2002, p. 6). Baird explains how these features can all be explored in a material sense whereby truth is replaced by function (i.e., in the material artefact itself). The application of knowledge within the context is often a key indicator of its status as knowledge within any one domain.

While technology employs knowledge from a range of other domains, *Device* knowledge is a term used unique to technology literature (Gott, 1988). It is argued as important in technology as it has as its referent the 'material' rather than 'natural' world. As such, device knowledge would appear to be in keeping with Baird's suggested epistemological shift from propositional 'truth' to 'function' and reflects the knowledge that successful artefacts bear – in both symbolic and literal ways. Device knowledge can be argued as existing as both tacit and explicit knowledge (Compton, 2004).

From this discussion it can be seen that the concept of technology has implications for both understanding the purpose of technology as a creative and intervening force in the man-made world, as well as implications for the purpose of technology education. This will involve an understanding of what makes technology a discipline in its own right which will be discussed in the later section.

2.3.4 Philosophy of Technology

This section will discuss the philosophy of technology by highlighting the relationship between humans and their surroundings and will make the link to the social and ethical considerations.

There are philosophical aspects of technology as there are to all things of importance in human endeavour and destiny. The following discussion of approaches will convey an impression of the fragmented field that is the philosophy of technology. In philosophical-anthropological studies, the starting point for understanding the philosophy of technology is the human being's surroundings and relation to nature (Schummer, 2001). The human being is considered dependent upon needs for survival in his/her surroundings; technology becomes the substitute for biological shortcomings and is therefore determined to a large degree by the nature of these shortcomings (Brey, 2000). For Heidegger (1977), such a characterization of the essence of technology is just not enough; an answer at the metaphysical level is also needed. For him the essence of technology is not that it is a means to some end: technology opens a channel to what was hidden and does not by itself present itself (Heidegger, 1977). In Dessauer's (1927) metaphysical approach, invention is the essence of technology and the ontological conditions that make invention possible are explored.

The social philosophy of technology focuses on the relations between technology and social, economic and political structures (Wartofsky, 1979). It analyses technological development as a social process and addresses the problem of who controls and monitors its development. One of the key problems in this field is whether technological development is primarily determined by its context (social shaping of technology), or whether technology determines the social context including its systems of norms and values (a position often attributed to Marx). This seems to be a complex notion which either way is advantageous for the society.

Consideration of ethics takes a significant place in the philosophy of technology. New technological possibilities for human interventions result in the confrontation of new moral problems. Arguments in favour of the introduction of new ethical principles are based mostly on the idea that modern, science-based technology is essentially different from earlier forms of technology (the crafts), and that its impact on man and nature is of a different order (e.g., the consequences of applying modern technology are no longer limited in space and time (Jonas, 1984). Today, technology can be said to be essential to science for purposes of measurement, data collection, treatment of samples, computation, transportation to research sites, sample collection, protection from hazardous materials, and communication (American Association for the Advancement of Science (1990), project 2061:Science for all Americans). New instruments and techniques are being developed through technology that makes it possible to advance scientific research. Even though the invention of the steam engine was a technological advancement in itself, the theory of the conservation of energy was developed in large part because of the technological problem of increasing the efficiency of steam engines. Thus it can be said that the modern technologies tend to use and derive knowledge from science, even though older technologies were successful in shaping and fulfilling immediate needs without a scientific base.

Another issue in this field concerns the claim that technology itself, as a system of means, is ethically neutral. Arguments against the neutrality thesis attempt to show that the conception of technology as a mere system of means is inadequate, because its impact on human life stretches much further; it replaces the natural with an artificial environment.

After reviewing a range of views of technology, the following section examines arguments as to why and what technology should to be taught in the form of technology education.

2.4 Technology Education

The aim of this thesis is to contribute to the epistemology of technology education to understand how the integration of science, mathematics and technology takes place in a technological design context. This introduction gives a brief overview of technology education and a philosophical introduction to the study of technological knowledge. It is followed by discussion on the various forms of knowledge in technology and technology education.

How technology and technological knowledge are classified, defined and described is important for technology education, as they affect what is to be taught as well as how to integrate and evaluate what has been learnt. Since the 1980s, in many countries, subjects like crafts or industrial arts have gradually been replaced or supplemented with more modern technology subjects, with a focus on the design processes, general problem solving abilities in addition to history and sociology of technology (even though its implementation was limited) (Norström, 2011). The introduction of this new subject, and attempts to fit it into an already crowded curriculum full of subjects with established content and strong support from academia, has initiated new research concerning the teaching and learning of technology. In this thesis, findings from a technology classroom are discussed and used to explain how teachers teach and students learn in a technological and social context to contribute towards the history, sociology and epistemology of technology. The philosophers in technology have not focused on the integrative nature of technology (Williams, 2011) and not much research on integration through technology has been carried out in this area. For me, writing from the perspective of an engineer-turned-teacher-turned-researcher, this idea seemed to be strange initially but not unfortunate, since the motivation and expertise was available at the University of Waikato. Even though philosophers, teachers and researchers approach technological knowledge from different angles, there are common areas of interest such as the explicit link of technology with other knowledge domains, how to demarcate technological knowledge from other types of knowledge, how to regard concepts from science and mathematics and their justification in the technological domain. The next section will examine the various perspectives on technology education which have implications in technology education.

2.5 Perspectives on Technology Education

Within education there exists diversity of concepts of technology resulting in a range of curricula foci. This relationship is complex as the same curriculum statement can often serve to support different, often contradictory, concepts of technology (Compton, 2004). Black (1994) discusses the diversity both between and within countries regarding the concept of technology and its purpose in education, identifying five different perspectives of technology within technology education. These perspectives range from traditional to more modern and advanced approaches. He begins with (a) Technology as craft skills, then extends it by adding (b) design, (c) "engineering science", then (d) amalgamates the second and third ['design & engineering science']. Lastly, he adds a further dimension, (e) practical capability of the pupil. Keywords like analysis, decision, manual, aesthetic, evaluation, collaboration, initiative, deciding and doing are part of the process.

There are various perspectives on technology education, but this study will focus on the perspective on technology and its educational purposes summarised from Black (1994) by Compton (1995), since his perspective aligns well with the New Zealand curriculum. Black (1994) discussed the approaches taken by countries already implementing technology education as falling into five different categories that reflect the differing perspectives on technology. The five perspectives, as summarised from Black (1994) are technology as craft skills; technology as design and make; technology and science; technology as design and make in the context of the application of scientific principles; and technology as practical capability. Further explanation include:

- *Technology as craft skills:* Here the concept of technology is primarily linked to making artefacts. The educational purpose would seem to be vocationally oriented.

- *Technology as design and make:* The concept of technology here is an expanded version of the first, in that it incorporates elements of design as distinct from making from prescription as focused above. Again the educational purpose is primarily vocational.

- *Technology and science:* The concept of technology here is essentially applied science - reducing often to applied physics. Educational purpose is considered vocational but in a very different sense to the first two. Links are made to general education - specifically for future citizenship of technological societies.

- *Technology as design and make in the context of the application of scientific principles:* The concept of technology here focuses on the process of design and manufacture. The focus also includes that of exploring the questions of purpose and value in the context of solving problems using scientific or mathematical concepts and principles. The educational purpose of this perspective would seem to be a more focused attempt to integrate cross-disciplinary knowledge to provide meaningful learning.

- *Technology as practical capability:* The concept of technology here is primarily centred around a complex process that focuses on co-operation, defining of needs, designing, implementing and evaluating solutions. Educational purposes are for "citizenship, broad vocational fitness, and personal development by way of the development of the synthesis of the powers of analysis, decision, manual and aesthetic skill, evaluation and collaboration", (Black, 1994, p. 114-115).

The development of technology education in New Zealand over the past decade has had the benefit of reflection on other countries' developments in the area (Ministry of Education, 2008). The concept of technology provided in the 2007 technology curriculum most closely aligns with Black's fifth perspective. However, the New Zealand position also has two additional aspects to the knowledge strands: technological knowledge and the relationship between technology and society. Whilst it could be argued these aspects are fully intended as being included in Black's notion of capability, they are given more prominence in the New Zealand curriculum, highlighting their importance to the concept of technology.

2.5.1 Technology and Technology Education

The relationship between technology and technology education could be described in terms of what it means for technology education in schools. Since its beginning in the 1980s, this practical hands-on training has gradually been replaced by more theoretical subjects, emphasizing product development, design processes, and the social effects of technology (Norström, 2011). The focus is on acquiring skills through practice and is much more than sanding, sawing and soldering, having moved to complex designing and general problem solving strategies (Cunningham & Hester, 2007; Lewis, 2004; Pavlova, 2006). Lewis and Gagle (1992) have argued in the past that technology educators "have two clear responsibilities; first to articulate the disciplinary structure of technology and, second, to provide for its authentic expression in the curriculum" (p. 136). Dugger (1988) and Zubrowski (2002) argue that technology should be considered a formal, academic discipline. Similarly, Waetjen (1993) emphatically stated that technology education "must take concrete steps to establish itself as an academic discipline" (p. 9). Even though technology as a school subject has been established in many countries, its true potential has not yet been fully explored.

Men and women have been engaged in the practice of technology since the beginning of history. Technology is not just about how particular devices work but also the explanation of why new technology came to being and why it took the form it did to contribute to the human culture. In the book *The Culture of Technology* (Pacey, 1983), a related point about technology has been made which compares medical practice with technological practice. Pacey draws an analogy with medicine arguing that medical practice has not only a technical aspect, but also an ethical and organisational element to it, and that the same is true of technology practice. Thus a more elaborated meaning of technology is generated in conjunction with the technical/practical aspects; the other inevitable organisational and cultural aspects are associated with technology practice. Hence, technology education has to incorporate not only the design process or a means to satisfy a need, but to incorporate the broader meaning of technology and its influences in the society.

The practical dimensions of technology in education are significant as many educators believe that opportunity should be provided to students to do technology in schools if they are to understand its principles and methods (Dugger, 1988; Waetjen, 1993; Williams, 2000). This component is essential but technology education should aim for more than just to give practice. There are many cognitive skills that can be acquired through technology education (Williams, 2000). Learning needs to have some rationale that makes sense to the individuals undertaking it. This can be accomplished through technology education by actively involving students in the learning process so they can make logical connections to contexts. Such learning situations should be mediated through tools and other artefacts which lead to the construction of knowledge. This will allow students to acquire knowledge and skills as a result of doing and understanding technology.

A sound relationship exists between technological activities and technological knowledge, and hence the knowledge which is classified as uniquely technological must be identified since it is different from the more established disciplines (Vincenti, 1984; Frey, 1989; Compton, 2004). The other forms of knowledge should also be identified like scientific and mathematical knowledge since they relate to technology and are contextual in nature. Thus, technology education in schools must be designed with a vision to provide students with the opportunity to identify and use knowledge from various domains through the practical nature of technology.

2.6 Technology Education in Schools

There is a human need to provide creative solutions to problems arising from wants, and this mostly is referred to as technology in the literature (Kogan-Bernstein, 1959). Technology practice is fundamentally an application of techniques to solve human problems. Throughout the centuries, these abilities to solve problems through the design, problem-solving, production, and invention have improved the quality of human life. Quality of life is to some extent related to an ability to develop new technologies creatively while simultaneously appreciating scientific, economic, social and ecological considerations (Makgato, 1999). Continuous rapid industrialisation and technological change place new demands on schools to develop the technologists, scientists, engineers, technicians and skilled workers who would continue to propel the economy towards a stable future (Herschbach, 1997a) and the acquisition of technological literacy for the general population. There are several studies demonstrating that design can significantly advance academic, creative abilities and cognitive function (Hetland, 2000; Seeley, 1994). The coming sections will highlight the purpose of technology in schools viewed from an international perspective.

2.6.1 International Context

In many countries, school technology has traditionally been closely connected either with technical education or industrial arts (Herschbach, 1997a). In some countries like Sweden, Scotland, England, New Zealand, Australia and several states in the United States, technology education has its roots in some kind of wood, carpentry, sewing, metal shop work or cooking. Beginning in the 1980s, this practical hands-on training was gradually replaced by other vocational subjects, with an emphasis on the design processes, product development and social effects of technology. The skills practiced eventually changed from wood, carpentry, sewing, metal shop work or cooking to design and general problem-solving strategies (Cunningham & Hester, 2007; Lewis, 2004; Pavlova, 2006). Acquiring these skills is still important but they cannot be seen as an end in themselves since there is much greater potential to acquire contextual technological knowledge. Today's focus on technological knowledge has shifted from technical know-how, to socio-technical understanding, functional rules and structural rules. These types of technological knowledge as presented by Ropohl (1997) will be discussed in detail in the coming sections.

In the United States, the purpose of technology as a school subject is to make students technologically literate: "A technologically literate person understands, in increasingly sophisticated ways that evolve over time, what technology is, how it is created, and how it shapes society, and in turn is shaped by society" (ITEA, 2007). This implies that students should acquire the fundamental technological knowledge and skills necessary to be an autonomous agent in a technology-based society. The English approach is somewhat different since they have technology as a national curriculum, but the goals seem to be similar. In England, the school subject is called *Design and Technology* (D&T) and has a strong focus on the design process (Banks & McCormick, 2006). The curriculum states that students should become capable to intervene in a technologically advanced society. For instance, Kimbell (1997) described capability as "that combination of skills, knowledge and motivation that transcends understanding and enables pupils creatively to intervene in the world and 'improve' it" (p. 12). Such capability provides pupils with a bridge between what is and what might be. Thus, pupils are expected to develop the capacity to identify things which need improving or creating in the world, and in response, design and make something that will bring about the desired improvement (Kimbell, 1997; Kimbell et al., 1996). The goal is that students should learn to design, problem solve and develop artefacts and thereby become capable of intervention in the technological world. In the United States, students design artefacts to learn about the technologies involved: in England, students design artefacts to learn about the design process (Kimbell & Stables, 2008). In England, the design ability is a goal in itself; in the United States it is often seen as a means to an end. The English students were expected to learn how to design and make objects; the American students were expected primarily to understand the technologies involved and their interactions with their surroundings and society.

In Sweden the situation is different. Technology is a subject with its own curriculum from grade one. It includes aspects of technology such as technological systems and technological processes (Lgr 11, 2011), similar to England. In Sweden, technology was established as a compulsory school subject in the mid-1980s. The first syllabus for technology was written in 1994. A slightly revised version (Skolverket, 2008) was used until the spring term of 2011. This syllabus was vague, and many teachers found it difficult to understand. According to the few studies of classroom reality that have been conducted, the subject's contents varied considerably between schools and individual teachers (Teknikdelegationen, 2010). As technology is a relatively new school subject, adequate training for the teachers was an issue, and as there are no national assessment tests, there are good reasons to believe that the way technology is implemented in school varies more than other school subjects. The design of artefacts and construction of physical models from cardboard, string, and drinking straws often have prominent positions among the activities performed in Swedish technology classrooms (Norstrom, 2011). Since the beginning of 2011, a new curriculum has been introduced (Skolverket, 2010) which identifies some central areas of study such as mechanics, electronics, automatic control, technological systems, the product development process, and technology's relation to society, the arts, and the sciences.

This new subject, Technology, was seen as meeting the needs for a discipline which would be "both intellectually stimulating and legitimate in the eyes of career-minded students and their parents" (Medway, 1992, p. 4). The combined effort of these countries in shaping the status of technology and helping to identify it as an academic subject, but still much has to be done to realise its full potential. It has been the early efforts in the United Kingdom to take positive steps towards establishing international education standards for technology education (Reid, 2000), which have been most significant for New Zealand.

2.6.2 Technology Education in New Zealand

New Zealand (NZ) is a small former British colony in the South Pacific with a population of 3.9 million people, heavily dependent on overseas trade for its economy (Reid, 2000). Historically, a large proportion of New Zealand's exports, mainly agricultural products, went to the United Kingdom. In the past 40 years, New Zealand experienced a major adaptation to a fast changing world, with its largest exports now to Australia, Japan, the United States and China (Reid, 2000). New Zealand has moved away from its dependence on dairy, meat and wool exports, as the new industries of forestry, horticulture, fishing, manufacturing and tourism have become more significant (Department of Statistics, 1999). These changes, together with advances in associated technology, have created changes to the NZ economy and further intend to change the fabric of its education and society.

In 1990, the New Zealand government was influenced by the changes taking place in England and Wales to embark on a project to revise its school curriculum (Jones, 1996). In 1991, the New Zealand Minister of Education requested the development of a technology curriculum as part of a broad initiative to improve the achievement and technical literacy of the students. The initial development phase included a detailed study of technology education in other countries (Ministry of Education, 2007). The introduction of a subject called Technology in schools was a worldwide trend in that decade (Black, 1994; Mather, 1995). The technology curriculum in England and Wales had considerable influence on the curricular implementation in the 1995 New Zealand curriculum to establish technology in its own right (Compton, 2004). The lessons learned there became part of the development path of the New Zealand technology curriculum.

The Government of New Zealand undertook a revision of curriculum in 1990 under the banner of *The Achievement Initiative* (Ministry of Education, 1991). The objective was to explore ideas influenced by the curriculum reforms that were taking place in England and Wales. A Ministerial Task Group Reviewing Science and Technology Education was set up in 1991. This made numerous recommendations, the most significant being the development of a new technology curriculum. The report recommended a technological education for all students, to develop people who are creative, problem solvers, innovative, and resourceful, and who could combine enterprise, initiative, and imagination with knowledge and generic skills. The report went even further in its recommendations to include:

- the importance of teaching and assessing interpersonal, communication and broadly-based practical skills;
- a broad range of knowledge and skills recognized by assessment procedures;
- adequate teacher training and resourcing for technology education; and
- Maori input and inclusion of the use of Maori language. (Ministry of Research, Science and Technology, 1992, p. 5)

The University of Waikato was contracted to write a draft curriculum for New Zealand schools (Jones, 1996). Consequently, the current *Technology in the New Zealand Curriculum* was printed in 1995, and it has subsequently been implemented in schools (Jones, 1996). The achievement objectives of the curriculum have three strands: Strand A: Technological Knowledge and Understanding; Strand B: Technological Capability; and Strand C: Technology and Society.

Technology in the New Zealand Curriculum of 1995 was designed to give students an understanding of the culture, values and the social issues involved with technology. It was intended to bring the concept of technological literacy into the intellectual domain (Reid, 2000). Such an approach to technology is now deemed necessary for all students in order for them to function effectively in modern technological society.

These three interrelated strands of the 1995 technology curriculum provided a framework for teachers to develop programmes of technology as part of a balanced curriculum. The dominant learning theories underpinning the 1995 technology curriculum were socio-cultural in nature with pedagogical approaches seeking to embed student learning in authentic and empowering contexts (Williams & Jones, 2015). The *Technology in the New Zealand Curriculum* was published in 1995, but was not mandated for full implementation until 1999.

In 2001 a national stocktake of the technology curriculum was undertaken in New Zealand that included reviews of learning area curricula, international evaluations, and analysis of teachers' experiences of the curricula in practice. Findings from the stocktake were reasonably positive with respect to teachers' experiences in the implementation of the curriculum in New Zealand schools (Year 1-13). One third of the teachers from this study wanted to make changes to the 1995 technology curriculum in terms of making the curriculum more comprehendible and suggestions to include more learning and assessment examples. The data from the questionnaires also show that 70% of the teachers reported that the curricular statements were helpful in assessing assessments, but many also reported difficulties with assessment in technology.

Teachers also detailed a wide range of successful approaches which included the flexibility of choosing topics of relevance to students; practical, hands-on learning activities; a problem-solving approach; and group or co-operative learning approaches ((Williams and Jones, 2015). Secondary school teachers (Year 9-13) placed greater emphasis on the *technological capability* strand than other strands. There were also concerns raised by secondary school teachers regarding the level of knowledge and skills needed to cope with the requirements of the technology curriculum.

School-based technological practice was leading to: high levels of student engagement; increasing levels of ownership of learning; increasing levels of empowerment resulting in an enhanced ability to make decisions; and effective collaboration with others to make a difference to their own lives and developments in their immediate community (Compton & Harwood 2003; Jones & Moreland, 2003), as confirmed from the. results from the technology achievement standards and national research projects (National Education Monitoring Project). Teachers reported that the technological literacy of the students was often limited in breadth and depth and knowledge lacking in the level of critical analysis for informed decision making.

A review of the national curriculum and further policy work was undertaken in 2004 known as the *New Zealand Curriculum Marautanga Project* (NZCMP). A stronger focus was provided on the philosophical basis of technology and technological knowledge (Compton, 2004; Compton & Jones, 2004). The findings from the study and the new policy thinking helped to reconstruct technology around the current three strands in the New Zealand Technology curriculum- technological practice, technological knowledge, and the nature of technology. The three strands were seen to realise the aim of developing technological literacy of the students, in a broader sense as the nature this literacy was reconceptualised to be broader, deeper and more critical (Compton & France, 2007a).

Classroom based research which was carried out in New Zealand in the past 15 years provided a suitable platform to re-define the concept of technological practice (Williams & Jones, 2015). The components of *Technological Practice* and their supporting indicators of progression within them had been established, trailed and validated within New Zealand classrooms (Compton & Harwood, 2004, 2005). The *Technological Knowledge and Nature of Technology* (TKNoT) research project sought to establish the key components of the remaining two strands - technological knowledge and the nature of technology (Williams & Jones, 2015). The TKNoT research led to the establishment of the two remaining strands and three components with the Technological Knowledge strand. The three current strand in the New Zealand technology curriculum is as follows:

Technological practice

- Brief development
- Planning for practice
- Outcome development and evaluation

Technological knowledge

- Technological modelling
- Technological products
- Technological systems

Nature of technology

- Characteristics of technology
- Characteristics of technological outcomes

This framework developed through research provided a robust philosophical and theoretical base for ongoing curriculum development work (Williams & Jones, 2015). A draft of the proposed curriculum with levelled achievement objectives for each of the identified components was prepared for consultation in 2006 (Ministry of Education, 2006; 2007). Socio-cultural and constructivist theories of learning provided an underpinning basis for learning, with pedagogical approaches seeking to establish student learning in authentic contexts for students to make informed practices and to make students think critically by developing reflective decisions (Williams & Jones, 2015). The technology teachers were required to incorporate the three strands of the 2007 technology curriculum into their programs from 2010. This study intends to investigate the integration of science, mathematics and technology by observing the practices of a teacher trying to impliment the 2007 technology curriculum through a design project.

2.7 Philosophy of Technology Education

A philosophy of technology has implications for the essence of technology education and why technological knowledge is necessary for all citizens. References to Heidegger (1977) and Dewey have been among the most popular philosophical references in technology education studies (Compton & Jones, 2004). Heidegger's philosophy has been used to define technology and its relation to society.

Dewey's philosophy of education, especially the concept of learning by doing, has been popular in school science for a long time and has provided a starting point to define the nature of scientific knowledge as part of the nature of science (Jones & Compton, 2009). The action-oriented nature of technology is a starting point for similar explorations, providing an indication of categories that would seem important to think about when defining the nature of technology, including the nature of technological knowledge (Compton & Jones, 2004). The action-oriented nature of technology makes the concept fit for technology as well, at least for some of the areas covered by the modern technology subjects (Blomdahl, 2006; de Vries, 2005b; Volk, 2007).

So, while there is some kind of tradition for supporting views of the nature of technology and the strategies used to teach technology, areas like the artefact functionality and ethical considerations should be considered and not overlooked. There have been attempts to introduce other branches of philosophy of technology, like technological knowledge, study of artefact functions, and ethical and aesthetical aspects of technological work into technology education studies, most notably by de Vries (2005b) and Dakers (2006). There have also been a small number of articles published in *The International Journal of Technology and Design Education* about technological knowledge (de Vries, 2005a; Ropohl, 1997), the study of artefact functions (Frederik et al., 2010), and ethical and aesthetical aspects of technological work (Ankiewicz et al., 2006; Middleton, 2005). These philosophical works in technology education have implications for this study to understand and to further investigate the nature of technological knowledge and its relation to other knowledge domains (scientific and mathematical).

2.7.1 Essential Features of Technology Education

Technology is a fundamental aspect of human activity. The acceleration of technological change is constant in everyone's life (Compton & Harwood, 2003; Dugger & Satchwell, 1996). Technology, and certainly technology education, is more of an activity than a discrete body of content (Williams, 2000). Technology is considered to be critical to the success of individuals, and society, and to maintain the earth's ecological balance. According to Herschbach (1997b), technology is a multidimensional concept and it does not reflect a formal defined structure of an academic domain as do science or mathematics. For the definitions of technology, there is a knowledge and process base for technology that is quantifiable and changes with time. Technological knowledge includes the nature and evolution of technology, linkages, and technological concepts and principles. The processes are those actions that people take to create, invent, design, transform, produce, make, control, maintain, and use systems. They include designing and developing technological systems; determining, controlling and manipulating their behaviour; utilising them; and assessing their impacts and consequences. Both knowledge and processes are critical to the existence and advancement of technology. One cannot exist without the other, for they are mutually dependent. With technological knowledge, people engage in the processes, it is through the processes that technological knowledge is developed (Dugger, 1997). The process of designing and making a technological artefact hence affords the development of technological knowledge. There should be an understanding of what education is supposed to achieve before technology education can determine what is to be taught in the classroom. Significant debate over the past years has resulted in reasonable explanations of technology. Technology education should encourage students to study and understand (a) the processes used by practitioners (technologists) to develop new technology. The processes include research and designing (b) the areas of technology which represent the accumulated knowledge of practice; and (c) the impacts of technology on society and the environment (Wicklein, 1997).

After highlighting some essential features of technology, the following sections will discuss the various types of technological knowledge in detail since it is crucial for this study to identify the classification of technological knowledge and how it differs from the more established domains of knowledge like science or mathematics. The following section will highlight technological knowledge, its various forms and classification and will further elaborate on how this form of knowledge is expressed in the school contexts.

2.8 Technological Knowledge

Technological knowledge is that which underpins technological activity, such as the use or creation of technological artefacts/products. Knowledge is of many different kinds and from various domains.

The defining characteristic of technological knowledge, however, is its relationship to activity (Herschbach, 1995). Technological knowledge has its own abstract concepts, theories, and rules, as well as its own structure and dynamics of change, which are essentially applications to authentic situations. Technological knowledge is a product of human activity, in contrast to scientific knowledge, which assists in explaining the physical world and its phenomena. As Landies (1980) observes, while the intellectual is at the heart of the technological process, the process itself consists of "the acquisition and application of a corpus of knowledge concerning technique, that is, ways of doing things" (p. 111). It is through technological activity that technological knowledge is constructed and defined.

There are essential differences between the science-based knowledge used in advanced engineering and the skills of the blacksmith, even though both are technological when applied and both are about objects. By watching a piece of metal and feeling its change in ductility and elasticity as the temperature varies, the blacksmith knows when the moment is right to start shaping it, but he may be unable to describe the science behind such a phenomenon. He has learnt it from practice and experience and his knowledge is not amenable to description in written form. The application of scientific knowledge is only useful when reconstructed, combined with other forms of knowledge and adjusted to the situation at hand (Layton, 1991). The blacksmith's tacit knowledge, to create a technological product, is technological in nature. Technology comprises much more than the application of scientific knowledge (Esjeholm & Bungum, 2013). Nevertheless, science and technology are highly interrelated: not only does modern technology build on advanced scientific knowledge, but the advancement of science is also highly dependent on technology (Bungum et al., 2016). These forms of knowledge will assist this study to focus on the ways students and teacher work in a technology classroom to co-construct technological knowledge through application.

The taxonomy presented by Ropohl (1997) recognizes five different types of technological knowledge: socio-technical understanding, technological laws, structural rules, functional rules and technical know-how. Much of what could be referred to as technological knowledge fits into these categories, but not all. For example, knowledge about which standard components are readily available in the market is very useful in many technological activities, but cannot be completely squeezed into Ropohl's categories. The technological laws are characterized by their justification methods, while the rest are characterized by their areas of application. In spite of some drawbacks, Ropohl's categorization is still useful. The categories are easy to understand and the inclusion of the categories above makes it fit for the study of the integration of knowledge, which tends to include the making parts of technology as well as the study of its relations to society.

Other taxonomies of technological knowledge were presented by de Vries (2003) and Hansson (2011). The taxonomy presented by de Vries is based on an attempt to apply Vincenti's (1984) categories to a different area of technology, namely the manufacture of semiconductor devices. He found that knowledge gained through trial-and-error and experience played an important role. To complete and refine Vincenti's categories, de Vries suggested modifications that would better comply with other areas of the philosophy of technology: functional nature knowledge and physical nature knowledge, that refer to the dual nature of technical artefacts (de Vries, 2005b; Kroes & Meijers, 2006), and action knowledge, that refers to studies of artefacts from a perspective of theory. Hansson (2011) presents a simple typology for technological knowledge by identifying four different categories of technological knowledge: tacit knowledge, practical rule knowledge, applied natural science, and technological science. The first two compare roughly to Ropohl's (1997) categories of technical know-how and functional rules. Hansson divided Ropohl's technological laws category into two further categories depending on their origins. Applied natural science is based on science which has been developed and justified using experiments and systematic testing, yet without being based on the natural sciences (Hansson, 2007). One of the advantages of making this a category of its own is to stress that even advanced technological knowledge need not to be founded on the natural sciences, as formulated in a scientific language and using mathematics.

The following sections illustrate the different forms of technological knowledge which will further assist in differentiating what knowledge is scientific and mathematical in nature.

2.8.1 'Knowing How' and 'Knowing That'

The division of knowledge into knowing that and knowing how was made by Ryle (1949). Knowing that is basically propositional or adopted, while knowing how is about knowing how to perform action. Knowing how is justified through experience, while knowing that may be justified in other ways, for example through literature. It is possible to know how to different degrees, like being a bad or a good driver, or a bad or a good cook. In the technological knowledge domains, this division is a bit awkward. There are types of technological knowledge that avoid Ryle's classification system, for example written rules of thumb or standard procedures for technological activities. Rules that describe how to reach a particular result, for example how to adjust something or how to operate some machinery, are a few examples of know how in the form of knowing that. If knowing that following the rules leads to knowing how to perform the action, the border between the two knowledge types is unclear and in practice often impossible to draw. Technological knowledge is in essence action-oriented, which makes the demarcation of knowing how and knowing that difficult and unclear: knowing that in the technology domain is supposed to guide action, just as does knowing how. Growing literature also refers to technological knowledge which includes understanding the physical and social environment of any technological development or site (Compton & Jones, 2004). Technological knowledge also comprises appropriate ethics, legal requirements, cultural or domain protocols, and the personal/collective needs of the users and technologists specific to the development as well as the site where the outcome(s) of the development may be located (Compton & Jones, 2004). This seems to be the same as Ropohl's social technical knowledge.

In the revised New Zealand Curriculum of 2007, the knowledge of materials and systems is expected to enable students to infuse their technological practice with advanced technological understanding and support more informed material selection and manipulation in their decision making (Compton, 2007). As such, the Technological Knowledge strand focuses student learning in technology around knowing that. Learning experiences focused on the Technological Practice strand are expected to allow students to gain a sense of empowerment as they undertake their own technological practice to find solutions to identified needs and/or realise opportunities. This strand also provides opportunities to embed the philosophical ideas from the Nature of Technology and Technological Knowledge in order to better inform their practice. As such, the Technological Practice strand focuses student learning in technology around know how. According to (Harwood & Compton, 2007), the two knowledge types, know how and know that combine to provide students with knowledge types seen as important in developing technological literacy.

2.8.2 Prescriptive Knowledge

Much of the technologists' professional knowledge is prescriptive (Norström, 2011); it regulates how the work should be done. Some of these prescriptions are demanded by policy makers, laws, ethics, engineering practices and other types of official rules and regulations, for example an overhead electrical wire has to be placed at a minimum height of 4.5 metres for voltages lower than 1000V (Elsäkerhetsverket, 2008), or that lights that indicate emergency evacuation should be red (Arbetsmiljöverket, 2008). Others are not regulated in official documents, but by tradition and habit. Examples of the latter include the placement of buttons on telephones and calculators or that the driver's seat is placed onto the right hand side (well at least in some countries). These rules are often not made explicit, but deviation from them does not always render an artefact useless in a certain context. These examples show that technological activity is influenced by its environment. The regulatory traditions and rules are required for the successful creation of artefacts and are part of the technological knowledge domain.

Mokyr (2002) deals with "useful knowledge," that is, knowledge that deals with "natural phenomena that potentially lend themselves to manipulation, such as artifacts, materials, energy, and living beings" (p. 3). Prescriptive knowledge comprises techniques, designs, and instructions; prescriptive knowledge may be embodied in an artefact - Mokyr uses a piano as an example of a device whose use is obvious in its design, which implies knowledge not only underlies design, but it is also manifest in design and designed devices.

The next section will look into how explanations and prediction fit into a category of technological knowledge.

2.8.3 Explanation and Prediction

The purpose of this section is to identify a reasonable interpretation of explanation and prediction in a technology education context since technological knowledge could have elements of both explanation and prediction within a design context.

An explanation is some kind of description, intended to increase the understanding of how something is related to something else. In the sciences, a typical explanation shows how some phenomenon brings something else about, using established laws of science. Explanation is mentioned in the Swedish curriculum, in the assessment criteria (Skolverket, 2011a), and in the commentary material for teachers (Skolverket, 2011b). Being able to explain a phenomenon, a mechanism, or a design principle is a sign of deeper understanding than just being able to describe it (Norström, 2011). The deeper understanding of how different parts interact to satisfy a purpose is, for example, mentioned in connection with explanations (Skolverket, 2011a). However, there is no proper definition or comment to how knowledge, explanation, and understanding in a technological context might differ from their counterparts in other school subjects (Norström, 2011). This type of explanation is not very common, and of limited use in technology. The main reasons for this are the users' and creators' focus and intentions that play a major role in technology.

The users' and creators' intentions must be considered. The results of manipulating artefacts depend not only on scientific laws, but also on the intentions of the agent doing the manipulation (Norström, 2011). There have been some fundamental attempts to analyse the users' and creators' intentions and knowledge while providing technological explanations (e.g., de Ridder, 2007; Houkes, 2006; Pitt, 2009), but there is still more to be done and this study intends to highlight this area. This lack of philosophical theory is a serious drawback for technology education studies in identifying what constitutes technological knowledge in an integrative environment. Knowing what constitutes a good explanation in technology is important for the choice of teaching methods as well as for the assessment of students' work (Norström, 2011).

In technological practice, prediction is generally more important than explanation (Norström, 2011). It is often enough to be able to predict how a certain component will function or behave in a certain context; the laws of nature that bring this about matter very little to the designer or practician. Explanations could be useful when refining processes and improvements to the artefacts have been made, but for everyday work the ability to predict is generally enough (Norström, 2011). This can be shown through many historical examples. Medieval metallurgists could predict that steel would become harder if heated until red-hot and then quenched in water or oil. They could not explain the scientific reasoning behind such an observation which demands an understanding of the crystalline structure of the steel; information that would not be available until several hundred years later. However, their ability to produce both mild and hard steel was sufficient in those days. In science, the situation is different, as the product of scientific work is knowledge, and explanations are necessary to show how different pieces of scientific knowledge support each other. Scientific knowledge could have been used to make improvements to the quality of steel which may in turn affect its process of production.

2.8.4 Non-scientific Technological Knowledge and Its Justification

An advantage of classifying this as a category of its own is to stress that even advanced technological knowledge, formulated in a scientific language and using mathematics, need not be founded on the natural sciences and can be justified through experience.

The existence of technology goes beyond the sciences; at least some technological knowledge exists without any scientific justifications (Norström, 2011). Even today, and even in technologically advanced professions such as computer programmers, doctors, dentists and electronics engineers, a significant amount of their professional knowledge is not based on science. An instrumentation engineer might know that a certain instrument does not give reliable results at high temperatures, even though the data sheet says they were calibrated. A lab technician may not know the scientific reasoning behind such an observation but his practice and experience makes him operate the instrument just like an engineer who may in turn know the reason behind the observation would do. There are examples of technological knowledge which enable or improve technological abilities that are justified by experience and practice, rather than by scientific explanations. Some of it, like the measuring instrument that does not comply with its data sheet, could be justified using established scientific methods. Other kinds of technological knowledge cannot be justified, for example, those based on standards, conventions and codes (Norström, 2011). The insulation of the earth wire should be striped in yellow and green according to electrical installation standards. These are the codes of practice followed by the electrical companies which have no proper justification as so why those particular colours were chosen for the purpose. An icon depicting a stylized 5mm disk is commonly used to symbolise the save command in a Microsoft Office Word documents. These are highly useful pieces of technological knowledge for electricians and computer users respectively; they are conventions and practices that are generally agreed upon and do not have a justification in natural sciences.

Among the non-scientific technological knowledge is the tacit knowledge that has attracted the most attention in recent years (Norström, 2011). The concept was popularised by Polanyi (1967), a chemist turned philosopher who used it to describe knowledge (or skills) that are difficult or impossible to verbalise but can be replicated by practice. A common example is that of riding a skateboard. To describe how to actually behave to retain the balance on four wheels is much more difficult than doing it. To learn how to ride a skateboard from written or oral instructions is practically impossible; it must be learnt by experience. The situation is similar in many crafts and also in professions that are seen as highly theoretical and science-based. The experienced health professional can often make a correct diagnosis within his area of expertise without making a full examination. Knowledge like this can only be learnt through experience (Nightingale, 2009).

Other types of non-scientific, experience-based knowledge are less discussed in the literature. This includes various types of rule-based knowledge as well as knowledge of standard solutions and procedures. These can typically be described in writing and such knowledge is easily transferred from one person to another. They may have their origin in trial-and-error procedures, experimentation, observations, experience or scientific knowledge. Often, the rules themselves do not disclose their origins. They are ultimately justified through repeated successful use over years. This experience-based knowledge includes what Ropohl (1997) calls structural rules: knowledge about how components interact. This does not specifically demand any scientific knowledge; the components can be seen as black boxes, defined by their inputs and outputs.

The users of these kinds of knowledge are often unaware of their origins and are sometimes led to believe that they have a scientific foundation. Rules for metal extraction from ore may be derived from a theory developed in the early 1700s, phlogiston theory, which was the best available theory for combustion and metals turning to calx (metallic oxide) and vice versa (known today as oxidation and reduction) (Bowler & Morus, 2005). Its users certainly believed that conclusions drawn using the theories could serve as justification of procedures for metal extraction. It has since been shown that phlogiston does not exist and it therefore cannot be used to justify knowledge about how to turn ore into metal. The procedures themselves are nonetheless useful, as they produce the expected results. The usefulness of a procedure could be evaluated by looking at the efficiency of the end results. It might be barely useful in one context, while optimal for other. The efficiency of a procedure can be viewed as a measure of the resources that are needed (material, economical, temporal, social) and in what amounts. As the procedure of heating coal with ore to get iron has proven to be both effective and efficient over and over again, it is rational to believe in its usefulness. The procedure was really justified through repeated use and its success.

All the various categories of technological knowledge are related to the task involved, the knowledge used within technology is context-bound and is often gained through practice. This study will focus on all the categories of technological knowledge since it recognises that a context weaves in the different categories together. It is important to remember that all forms of knowledge can influence each other or be influenced by other forms (Alexander et al., 1991). Knowledge, whatever its structure and form, is interactive, contextual and useful for this study.

2.9 Technological Knowledge in Technology Education

It is hoped that the results from this research will add to the epistemology of technology and will be useful in the planning and delivery of integrative learning in a technology classroom. This study will provide a starting point for discussion about how technological knowledge and knowledge from science and mathematics integrate in the design process.

The philosophy of technology defines the types of knowledge that would be useful when discussing these themes in technology education (Norström, 2011). If school technology mainly aims to be about acquiring the knowledge and skills necessary for students to be autonomous agents in modern society, then a strong emphasis on the socio-technical understanding is necessary (Norström, 2011). School technology should include the history and sociology of technology, for example how technologies like railways, televisions, radios, phones and computers have changed everyday life, and how new lifestyles have caused demand for certain products and how technology has affected society at large and vice versa. A focus on the history of technology will enable students to realise the form of technological knowledge evolving over time. Being a technologically literate person demands some knowledge and understanding of the artefact level reference; how the individual artefacts are used and for what purpose, what standard mechanisms they utilise, and the technical aspects of socio-technical systems (Norström, 2011). Using the terminology introduced by Ropohl (1997), the artefact and system studies should be dominated by socio-technical understandings, functional rules (in terms of what to do), and structural rules (rules underpinning the assembly of a system). Together, these allow pupils to develop a technological knowledge that enables an understanding of much of what is going on around them. Technical know-how must be included to some extent in the classroom because without fundamental skills in, for example, tool handling it is very difficult to do experimental work in technology. In New Zealand, students develop practical skills in the technology classrooms while designing and making. These skills do not need any prominent positions in the technology curriculum (Norström, 2011) since they are an implicit part of the design process.

Technology is different from science in that its purpose is to find what is useful, often in specific contexts, rather than what is true or generally applicable (Norström, 2011). If school technology is to resemble authentic technology to some extent, this view must pervade the work performed by students and also allow the utilisation of knowledge from various domains naturally in a design context. Students should be allowed, and even encouraged, to use mechanisms and ideas developed by others as well as a trial and error method so they develop skills necessary to perform technological work. If school technology can use school science and mathematics, this approach could provide a deeper understanding of both subjects and the ways they interact in a design context.

However, technology serves a different purpose in the school curriculum. Science, mathematics and technology represent different epistemologies, traditions and approaches to knowledge acquisition and usage, and so the interaction among them should be studies within a technological context. Knowledge of the relevant principles of science and mathematics introduced with the philosophy of technology in a suitable context could provide teachers and STEM educators with a deepened understanding of the distinctive features of science, mathematics and technology respectively. This could improve the quality of teaching as well as setting up a platform for integration through the co-construction of technological knowledge which can happen naturally in a technology classroom.

The next section will look into the technological design process and will attempt to elaborate the knowledge generated through that process. It will also differentiate the design process from problem solving.

2.9.1 Technological Design Process and Problem Solving

The definition of technology education has evolved to reflect the true nature of technology, since “much technological activity is oriented toward designing and creating new products, technological systems, and environments” (International Technology Education Association, 1996, p. 18). While there are many definitions of technology (Dyrenfurth, 1995), a number of them are oriented toward a product design and problem-solving model. Wright and Lauda (1993) include these elements in their definition of technology as “a body of knowledge and actions, used by people, to apply resources in designing, producing, and using products, structures and systems to extend the human potential for controlling and modifying the natural and human-made environment” (p. 3-5). Problem solving and product design are not the same (Flowers, 1998).

There seems to be a lack of consensus in the literature (Ulrich & Eppinger, 2008) as to what constitutes process in technology. Some advocates propose a design process as used in England and Wales and others propose a problem-solving process as was evident in Scotland (McCormick, Murphy & Hennessey, 1994). The activities represented by a design process are not the same as the activities of problem solving, although they do have some overlap (Shield, 1996). The main difference is that the design process requires the students to “call upon the intellectual application of knowledge, skills, attitudes, perceptions and values as opposed to problem-solving which is a form of learning used to acquire knowledge and concepts” (Shield, 1996, p. 3). There appears to be very little difference in the way the design processes and the problem-solving processes are described in the literature. To some authors, design and problem solving are synonymous (Johnsey, 1995), which this study does not agree with. This study focuses on the design process as it aims to understand the integrating of science, mathematics and technology in a technological design context where problem-solving is an integral part of the process. This study will take a closer look at both the design process in the broadest sense and problem solving because both processes are integral to technological activity.

Problem solving is seen as a broad skillset which should be taught to all students. Popper (1999) argued that “all life is problem solving” (p. 99) and that the basic elements of all problem solving are (a) recognizing the problem, (b) attempting alternative solutions and (c) eliminating approaches that do not work. The advocates of this concept (McCormick et al., 1994) regard the process as more important than the content knowledge needed to solve the problem. Technology education is seen as supporting problem-solving activity (Dorst, 2003; Vandeleur, 1997), while designing and making. Johnsey (1995) argues that technology is not the only way of solving problems; the solution to solve the problem is technological itself, if it involves designing.

One of the reasons technology education is in the school curriculum is that designing involves generating ideas and trying to develop new and innovative outcomes, thereby providing a rich learning experience (e.g., Harel, 1991; Harel & Papert, 1991). There have been numerous attempts in the past to describe what the design process consists of in technology. Most researchers have posited normative models for learning to solve design problems (Dym & Little, 2004), referring indirectly to the design process. Early models of technological activity described it in simple problem-solving terms, starting with a problem and ending with an acceptable solution through a linear sequence of steps (Williams, 2011). However, with time, experienced educators realised that the design process is a cyclic loop on the reasonable grounds that the results of the evaluation of the final product will further provide new problems to start the cycle again.

There is a range of activities students undertake when engaged in a design and technology task. The sequence of activities is convoluted and complex and is different each time they design (Williams, 2011). Thus, the process may be variously considered as cyclic loop, iterative or recursive in nature (Queensland School Curriculum Council, 1999), an interaction between “mind and hand” (Assessment of Performance Unit, 1994), an interrelated process involving several planning-making-testing loops (Ritchie & Hampson, 1996) or an interacting design loop (Kimbell, 1997) with the goal of creating a product. Even professional designers reject the notion that they can represent their work by an algorithm (Hennessey & McCormick, 1994). So both designers and experienced students seem to adapt inventive and flexible approaches according to the situation in which they are working. There are many activities in this process but the most important ones as listed by Williams (2011) are evaluation, communication, modelling, generating ideas, research and investigation, producing, and documenting.

Williams (2000) prefers to call these activities aspects rather than stages of the process; stages have a sequential connotation which is not appropriate as a technology process. It seems that technology education is process-driven and there is probably more international agreement among technology educators about the activity of technology than about the content of technology (Williams, 2011).

Technology education emphasizes practical planning and physical making as necessary sub-activities of the process, as indicated by the model in Figure 2.1.

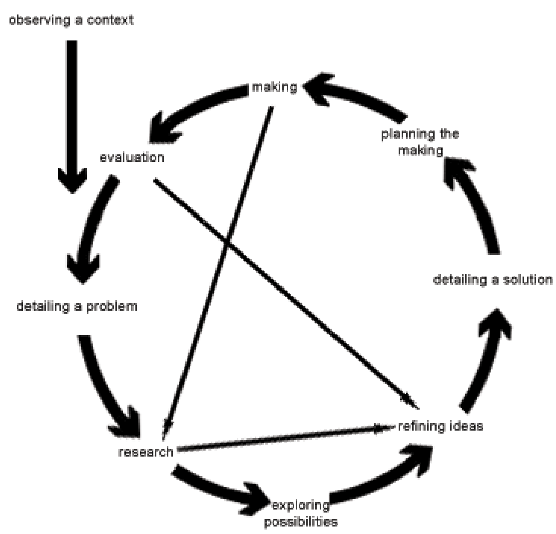


Figure 2.1. The Design Loop

Source: Hutchinson & Karsnitz, 1994.

The design process is often depicted as a "design loop" with different tasks to be accomplished. The tasks, too often seen as steps, should be considered as suggestive rather than prescriptive since the approach might restrict student's cognitive thinking skills (Williams, 2011). In actual use, there will be marked differences in how individuals pursue a task and implement the process. However, it is important that students become familiar with the cyclic model but do not attempt to follow it rigidly, as this could consequently impede the learning process.

The design process could start when students draw up the specification, exploring ideas to produce a design proposal and how to develop it into an appropriate design. Next comes the planning and making requirements where they should be able to produce artefacts, systems and environments, to work to a plan and to use the available resources, including knowledge and processes, appropriately. The various models of the design process suggest the experience students could have if they design or design and make an artefact. The practices and perceptions of the students while they design and make through their involvement in the design process will also open up possibilities for the integration of science, mathematics and technology.

2.10 Technological Knowledge within the School Context

There is no clearly generalizable, representative structure characterizing all of technology, as is found in physics, chemistry or biology. Technology includes its own abstract concepts, theories, rules and maxims but again, these are contextualised in the application (Herschbach, 1995). Technology demonstrates a potential to be included in schools as a discipline in its own right so that technology education will have greater appeal to the public as a subject with considerable potential for literacy. This means technology education can also emphasise the acquisition of knowledge and generic skills.

The following sections will discuss technology as content knowledge, process and contextual knowledge and how they are placed within the school context which has curricular implications and expresses technological knowledge in a sense which lacks coherency, independence and generalizability. These sections will highlight the forms of technological knowledge relevant within the school context, rather than the much broader meaning of technological knowledge.

2.10.1 Technological Knowledge in Schools as Content Knowledge

Up to the late nineteenth century, it was believed that technology was the application of scientific knowledge (Herschbach, 1995). It has been noted that the influence of science on technology has grown tremendously (Mackenzie & Wacjman, 1985) and the partnership of science and technology still exists in modern industry (Makgato, 1999). As far as technology education is concerned, the types of knowledge required will depend on the context of the technological design. Designing depends to a large extent upon the knowledge and skill base of the designer (Boon, 2006; Dugger et al., 1985). Technology draws content from across different fields of inquiry (Herschbach, 1995) and provides a way to integrate learning, not only with other fields, but with purposeful activity.

Technology education as content knowledge could be viewed as a stage of conceptualising where learners learn about concepts and principles used in technology activities (Fleer, 2000). The next type of knowledge, process or procedural knowledge, as when a solution to a particular need or brief is sought, is developed through processes (Williams, 2000).

2.10.2 Technology Education as Process

As discussed earlier, technology education includes a process to be taught to the learners. Technology, then, is not only content to be learned but includes the vehicle through which processes embedded in technological activity can be learned (Herschbach, 1995). With regards to this view, the subject technology is often referred to as design technology or design and technology (Foster, 1999). The technological process has been described by various authors in different ways (Layton, 1974; Vincenti, 1984; Williams, 2000). Design technology is about identifying needs, generating ideas, planning and creating, testing, and finding the best or optimal solution to the problem. The recognition of the centrality of knowledge leads to conceiving technology as more than artefact, and as more than technique and process (Layton, 1974; MacDonald, 1983; McGinn, 1978, 1990; Vincenti, 1984; Ziman, 2000). Landies (1980) observes that the intellect is at the heart of the technological process and it consists of “the acquisition and application of a corpus of knowledge concerning technique, that is, ways of doing things” (p. 111).

There is a range of activities in which students are engaged when they do technology in classrooms (Williams, 2000). The activities are not done in a set sequence when they work on a task. The activities undertaken depend upon the nature of the student and the nature of the problem (Williams, 2000). These aspects cannot be standardised for all students as that would force students into a way of thinking that has been predetermined by the teacher. Williams argues that following a set sequence of steps in technology can hinder the cognitive development of the students since the steps might seem to be prescriptive where less critical thinking skills are fostered. These activities in technology are not an end in themselves, but are carried out in a classroom so that the students can become independent problem solvers, creative and reflective thinkers (Dugger, 1988; Williams 2000). The aspects of technological process can help achieve the generic competencies that all students need and should have as generic skills (Bungum, 2004; Mayer, 1992).

The Design Process (Investigating, Designing, Making, Evaluating and Communicating- IDMEC) forms the backbone of the subject in schools and could be used to structure the delivery of all the learning aims (Barlex, 2005; Corkery, Grant, Roche & Romero, 2006). Learners should then engage in a complex process that allows them to develop solutions that solve problems, rectify design issues and satisfy needs (de Jager, 2011).

2.10.3 Technology Education as Context

Many instructional theories (like social learning, social development, etc.) focus on authentic tasks that help learners integrate needed knowledge, skills and attitudes, coordinate individual skills that comprise a complex task, and transfer their school learning to life or work settings (Rule, 2006). Collins's (1988) idea of situated learning: "learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life" (p. 2) also addressed knowledge applied in authentic real life contexts. The demands of teaching more challenging content to diverse learners suggest a need for understanding the meaning of authentic contexts in technology.

The separation between knowing and doing has traditionally been the hallmark of school and university learning (Resnick, 1987). The emphasis in school and university has been on extracting essential principles, concepts and facts, and teaching them in an abstract and decontextualized form (Herrington & Oliver, 2000**)**. Such an approach may result in failure to access or recall knowledge which may be relevant to solve a problem. Information is stored as facts rather than as tools

(Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990), is ‘welded’ to its original occasion of use (Brown, 1997) or as Whitehead (1932) suggested, the knowledge has remained ‘inert’. When learning is separated from context, knowledge itself is seen by learners as the final product of education rather than a tool to be used dynamically to solve problems.

Many authors believe that useable knowledge is best gained in learning environments that feature the following characteristics. The learning environments should:

- Provide authentic context that reflects the way the knowledge will be used in real life (e.g., Brown, Collins, & Duguid, 1989; Collins, 1988; Gulikers, Bastiaens, & Martens, 2005);
- Provide authentic activities (e.g., Brown, Collins, & Duguid, 1989; Cognition and Technology Group at Vanderbilt, 1990; Jonassen, 1991; Norton & Ritchie, 2009; Young, 1993);
- Provide access to expert performances and the modelling of processes (e.g., Collins, Brown, & Newman, 1989; Lave & Wenger, 1991);
- Provide multiple roles and perspectives (e.g., Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990; Honebein, Duffy, & Fishman, 1993; Lave & Wenger, 1991; Spiro, Feltovich, Jacobson, & Coulson, 1991);
- Support collaborative construction of knowledge (e.g., Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990; Brown, Collins, & Duguid, 1989; Esjeholm, B.-T., & Bungum, 2013);
- Promote reflection to enable abstractions to be formed (e.g., Boud, Keogh, & Walker, 1985; Norman, 1993);
- Promote articulation to enable tacit knowledge to be made explicit (e.g., Lave & Wenger, 1991; Pea, 1991; Vygotsky, 1978);
- Provide coaching by the teacher at critical times, and scaffolding and fading of teacher support (e.g., Collins, 1988; Collins, Brown, & Newman, 1989; Greenfield, 1984; Harley, 1993); and
- Provide for authentic, integrated assessment of learning within the tasks (e.g., Gulikers, Bastiaens, & Kirschner, 2004; Herrington & Herrington, 1998;

McLellan, 1993; Reeves & Okey, 1996; Young, 1993, 1995; Esjeholm, 2013).

In section one, various views on definitions of technology were provided. The commonality in all these views is that technology is about fulfilling needs by designing, investigating, developing and evaluating products and systems. It has been argued that the major programme goal of technology education includes "adaptive, critical thinking, innovative, problem-solving skills and development in all domains of learning" (Zargari & MacDonald, 1994, p. 10). Implicit in technology education is the emphasis on real world authentic problem solving and the incorporation of both mathematical and scientific principles across these domains, which remain the fundamental rationale for integrative STM education. Technological practice takes place within, and is influenced by, social contexts (Ministry of Education, 2007). Students should be provided opportunities to design and make artefacts/products within the context of his/her environment to foster meaningful learning. Herrington, Reeves, Oliver and Woo (2004) agree that learning environments should be authentic and relevant to the student in order to better engage them. Herrington and Herrington (2006) further posit that content be designed to be as authentic as possible by incorporating content and activities to reflect the way the knowledge is used in real life situations. Such learning activities would call for students to become active participants in their own learning processes, learn to solve problems and work collaboratively (Shield, 1996).

The discussions on the areas of knowledge for technology education have implications for STEM and an integrative learning environment since technology offers an environment where content from other domains could be integrated. This research studied the integration of science, mathematics and technology in a technology classroom in order to identify strategies for integration. The process of designing an artefact allows integration of ideas from various domains where creative or innovative thinking leads to fresh insights, novel approaches, new perspectives, and whole new ways of understanding and conceiving of things.

2.11 Technology Education as a Learning Environment

This section will further discuss technology education as a learning environment where generic skills could be developed through participation in an authentic context.

The quality of education that teachers provide to students is highly dependent upon what teachers practice in the classroom. Thus, in preparing the students of the twenty-first century to become successful individuals in society, technology educators should provide an authentic teaching and learning environment for the integration of science (Zubrowski, 2002) and mathematics (Norton & Ritchie, 2009). Technology is seen as providing rich contexts for learning and applying mathematics in authentic and relevant contexts, as well as developing more positive attitudes towards the value of the subject (Esjeholm, 2013). Students might benefit if teachers knew how students might use science and mathematics and how best to teach them in a technological design context because such an approach may help students to see the connection among the various disciplines and draw meaning from such an experience. Changing the traditional ways of teaching in technology, science and mathematics in the classroom has been a continuing professional concern (Furner & Kumar, 2007). Efforts and strategies could be developed to direct the integration of science and mathematics in a technological design context which could result in a more student centred approach.

Educators who help students develop their confidence and ability in fostering generic skills would have a positive impact on students' lives in the long term (Furner & Kumar, 2007). Furner considers it to be an obligation as an educational community to make the difference for the future of the students in an ever-growing competitive global environment, which depends so heavily on science, mathematics and technology. If schools do more in terms of integrating knowledge from various domains in an authentic real life challenging environment, they may be able to impact the lives of their students forever in terms of logical decision-making, interdisciplinary thinking, gaining technological literacy and having options for various career pathways.

Knowledge is growing ever more specialized and expanding exponentially. Shared decision-making, information sharing, collaboration, and innovation are essential in today's enterprises (Furner & Kumar, 2007). No longer can students look forward to a high standard of living in the conduct of low skill labour or use of routine skilled work that may be accomplished by machines or easily out-sourced to less expensive labour markets. Today, much professional success lies in being able to communicate, share, and use information to solve complex real world problems, in being able to adapt and create solutions in response to new demands and changing circumstances, and to command and expand the power of technology to create new usable knowledge (Pacific Policy Research Center, 2010).

Given the economic and political challenges of the shortage of skilled labour, students will need experiences which develop their skills to become better problem solvers and more creative innovators. Some authors (Carroll, 2007; Dede, 2007; Kalantzis & Cope, 2008; Fisher & Frey, 2008; Trilling & Fidel, 2009) and organizations (Partnership for 21st Century Learning, National Science Foundation, Educational Testing Services, NCREL, Metiri Group, etc.) strongly advocate that twenty-first century learning skills will enable students for the creative thinking, flexible problem solving and inventive, collaborative and innovative skills they shall need to be successful in work and life. The literature review begins by defining twenty-first century learning skills, and then moves on to address how these skills can be fostered in educational settings.

2.11.1 Twenty-first Century Innovation Skills and Learning Environments

Traditional education classrooms have often focused on the matter of the subject (science, mathematics, social studies, arts) and then assessed student content knowledge with examinations at the end of the school year. This is not sufficient for the twenty-first century. The desired learning outcomes of the twenty-first century learning frameworks, according to a report published by the Pacific Policy Research Centre (2010), include the learning of the traditional content in combination with the learning outcomes and innovative skills discussed in the following paragraphs.

Critical thinking and problem-solving skills include the ability of students to (a) reason effectively, (b) ask pointed questions and solve problems, (c) analyse and evaluate alternative solutions to the problem, and (d) reflect critically on decisions and processes (Pacific Policy Research Centre, 2010). Critical thinking is the ability to analyse, interpret, evaluate, summarize and synthesize information (Trilling & Fadel, 2009). With the advent of new technologies, and the increasingly complex expectations of employees, the traditional problem-solving skills of the twentieth century have to be reformed to what is required for the twenty-first century workforce as the level of skills and knowledge are both steadily rising, with no end in sight (Temple, 2001).

The twenty-first century is quite different from the past in the capabilities people need for work, citizenship, and self-actualization (Partnership for 21st Century Skills, 2006). The twenty-first century skills are different primarily due to the emergence of sophisticated information and communications technologies (Karoly, 2004). For example, the way work is carried out by people is continually shifting to computers and telecommunications as these technologies expand their capabilities to accomplish and ease human tasks.

Just as in business and industry, education must constantly adapt to the rapid shifts in this twenty-first century which calls for a culture of innovation informed by data, research, and critical and creative thinking. These skill sets are believed to promote creative thinking and the ability to work creatively with others (Wegerif & Dawes, 2004). Creativity is a skill often described as essential to be fostered among students (Wegerif & Dawes, 2004, p. 57). Creativity can be nurtured by teachers and learning environments (classrooms) that encourage questioning, openness to new ideas, and learning from mistakes and failures, with practice and over time.

Innovation is often used in conjunction with terms such as creativity, design, invention, and exploitation because creativity is regarded as a key building block for innovation and is a capability inherent in all human beings (Rosenfeld & Servo, 1991). Creativity entails a level of originality and novelty that is essential for innovation. Students need to act on their creative ideas to make a tangible and useful contribution to the field in which the innovation has to be made. According to Harvey et al., (1997 cited in Holden and Jameson, 2002), most employers today see creativity and innovation as driving productivity improvements across the economy.

2.11.2 Communication and Collaboration

Whether learning happens in schools, workplaces, or other environments, it is fundamentally a social activity (Brown, Collins, & Duguid, 1989). The communication and collaboration skill sets refer to the ability of individuals to communicate clearly, using written, oral and non-verbal languages, and collaborate effectively and responsibly with diverse populations with new communication challenges (Eisenkraft, 2011). It can be argued that the twenty-first century citizens need to have these skills to fulfil the demands of social relations in a global economy because education is also focussing on good communication.

Students should be able to articulate thoughts and ideas effectively using oral, written and nonverbal communication skills and share responsibility for collaborative work (Trilling & Fadel, 2009) in a variety of forms and contexts. Students should be able to use the language of science, mathematics and technology for a variety of purposes (e.g., to inform, instruct, motivate and persuade) in diverse environments.

2.11.3 Defining Current Learning Environments

Since a major component of this research is to understand the integration of science, mathematics and technology (STM) in a technology design environment, it is important to understand the learning environment in which students learn best. A learning environment has been defined as a "system that accommodates the unique learning needs of every learner and supports the positive human relationships needed for effective learning" (The Partnership for 21st Century Skills, 2007, p. 3). These learning environments comprise physical spaces, learning communities, materials and tools that encourage students to adapt and hone their skills. The environment should foster learning tailored to the needs and wants of the individual to acquire knowledge and skills through learning strategies and approaches that are personalized and adapted to the learner's own learning styles and preferences such that learning occurs when and where the learner desires. Cornell (2002) argues that learning needs to take place in contexts that promote interaction and a sense of community that enables formal and informal learning.

The school curriculum and teaching practices have been criticized because of their topic by topic approach that does not provide students any experiences in integrated real-world problems (Fortus et al., 2005). Real-world problems are defined as situations requiring solutions which are not clear cut, where requirements may conflict, to provide sound judgement according to the situation, and where optimization rather than proof or best fit is needed. This criticism of the school curriculum has called for a reformation around real-world issues relevant to students' lives, using innovative and real learning instructional practices that shall help students develop the knowledge and skills required in a science and technology-rich world (AAAS, 1993; Bartel et al., 1992; Blumenfeld et al., 1991; Lipman, 1991). A similar suggestion had been put forward by Sack-Min, the author of *Building the Perfect School* (2007) that the qualities of where we learn affect the quality of how we learn.

Interests of students should be aligned with their personal values to forge a common vision to pursue a problem of relevance in an environment that motivates them. A survey conducted in the United States by Konings et al. (2007) with tenth-grade students and teachers about their desired learning environments revealed contrasting differences in the perception of students and educators. Konings et al. concluded that when students had input into the design of their environments, they felt more successful, motivated and invested in their learning. In the same study, when a first-year high school teacher asked students to list factors that would make them more successful in learning, the students did not ask for more time to complete assignments and similar support, but that their learning would be best fostered in an environment that involves designing and in which they may pursue a problem of their personal interests in addition to their schoolwork (Brown, Murphy & Nanny, 2003).

An issue then is how to best prepare students for a future of work which requires creativity and innovation in an environment which motivates them. It is here that this research has potential to investigate integration for teaching in a technology classroom with a focus on real-world problem solving which supports a rich learning experience with a focus on training students with knowledge and skills they require. The following sections will discuss the goals and arguments for STEM education.

2.12 STEM Education

This section will review the STEM education literature. The rationale for introducing STEM has also been highlighted. The discussion provides a picture of school students losing interest in the STEM areas (Fortus et al., 2005). This has resulted in a skill gap which has adverse effects on both the intellectual skillset and the economy of a nation. Closing this gap has been a concern among politicians and educators. Numerous attempts have been made to integrate science and mathematics, with a recent focus on technology and its potential to do this. These aspects will be discussed in detail in the coming paragraphs.

The term 'STEM education' refers to teaching and learning in the fields of science, technology, engineering, and mathematics. It may include educational activities across all grade levels— from pre-school to post-doctorate—in both formal (e.g., classrooms) and informal (e.g., afterschool programmes) settings. STEM education is a political response to the need to change the current practices of teaching in schools and to adopt methods which provide rich learning experiences for all students by their active engagement in the learning process. A brief review of the literature about twenty-first century skills suggests that traditional teaching methodologies are no longer sufficient as the education and skills of the workforce are a critical element for successful innovation (North Central Regional Educational Laboratory (NCREL), 2003).

Evidence gathered from various K-12 science based design programmes (a pedagogy designed to support construction of scientific knowledge) suggests that children tend to generate low-level factual questions (Fortus et al., 2005) rather than questions that could extend their understanding (van Zee et al., 2001), they do not consider evidence systematically in formulating arguments (Linn, 1992), and are proficient at carrying out procedures with guidance but have difficulty focusing their attention on the reasons for these procedures (Krajcik et al., 1998). The traditional delivery system for mathematics and science instruction (i.e., teacher centred teaching) in elementary and secondary schools is obsolete in a technological era and fails to capture students' interest (Sanders, 2008). Teaching in STEM has to be fostered to accommodate the presentation of information and cultivation of techniques so the students' understanding does not fall short (Rosenblatt, 2005) and to motivate and spark students' interest in STEM careers through the practical aspects of technology. Therefore, the challenge now is to construct a learning environment in which students have significant opportunities to take an active role in their own learning. These findings support the need for STEM education to develop interdisciplinary thinkers who can consciously apply knowledge from more than one discipline (science and mathematics) to make connections in content that cut across subjects.

The literature indicates little clarity about how STEM education might be constructed in a classroom environment in terms of how the subjects could relate to each other (President's Council of Advisors on Science and Technology (PCAST), 2010). Effective measures have to be taken which require a detailed investigation of practices of students and teachers in a classroom to develop a model surrounding the design and delivery of an integrated instruction for STEM Education. A Congressional Research Service (CRS) report of 2012 to the Members and Committees of Congress also states that the economic and social benefits of scientific thinking and STEM literacy have broad application for workers in both STEM and non-STEM occupations. The term 'scientific thinking' has many definitions. In general, it refers to the skills, processes, and methods of Science. As such, many contemporary policymakers consider widespread STEM literacy, as well as specific STEM expertise, to be critical human capital competencies for a twenty-first century economy (Gerardi & Meier, 2010). There is a general consensus that engaging students in design could be beneficial for science and mathematics (AAAS, Project 2061, 1993) with studies demonstrating that design can significantly advance academic and creative abilities, and cognitive function (Hetland, 2000; Seeley, 1994; Willet, 1992).

2.12.1 Vocational Argument for STEM Education

Vocational goals of STEM education relate to the skill shortage in science and engineering areas. STEM has been introduced in the United States and the United Kingdom in an attempt to promote the flow of scientists, engineers, technologists and mathematicians (Department for Education and Skills, 2006; *SET for Success*, 2002). The UK seeks to position itself against global competitors at a time of rapid economic change, the priority of increasing its capacity for innovation and enterprise is becoming increasingly urgent (STEM Programme, n.d.), a goal set to be achieved partly through the promotion and national coordination of STEM activities (Williams, 2011).

This importance and potential of STEM education has also been realised by the New Zealand government in its report, *Growing the Pipeline of Work-ready Engineering Graduates* (2012). The report recognised that the majority of students entering first year engineering courses, even with the prerequisites, are inadequately prepared to study science, technology, engineering and mathematics (STEM) subjects at the tertiary level. The Tertiary Education Union (TEU) allocated nearly $42 million for tertiary engineering courses to attract more students (TEC, 2012) and to improve the STEM pipeline. Some of the key themes that emerged in the forum with the Tertiary Education Commission (2012), engineering education providers, industry representatives and government agencies were the need to raise the profile of engineering, to highlight the benefits of a career in engineering and emphasize the important contribution that engineering makes to both the economy and the community. The TEC supports the government's overall aims for New Zealand's economic growth with the vision to deliver greater prosperity, security, and opportunities and for all citizens to be equipped with knowledge, skills and values to be successful in the twenty-first century.

The political and vocational agenda for STEM education is about training young people with the knowledge and skills they must possess to become successful engineers or scientists, and to prepare people to think and function as a technologically literate citizen to fill the skill gap. Initiatives taken by the governments of US, UK and NZ are to encourage more students to pursue careers in STEM fields with an aim to create a lasting partnership that will provide students with the right knowledge, skills, tools and resources to educate and motivate them to complete STEM degrees.

2.12.2 General Argument for STEM Education

STEM education is also being proposed as a component of general education. STEM has the potential to improve the level of literacy (Department of Education and Skills, 2006) and overall problem-solving skills (Holdren, 2009) among the general population. These quotes from *Rising Above the Gathering Storm*, written by the Committee for the Presidents of the National Academy of Sciences, National Academy of Engineering and the Institute of Medicine in 2007 also emphasizes the significance of STEM education (general and vocational) for the literacy of society by stating:

> Without fundamental knowledge and skill (in mathematics and science), the majority of students scoring below this level (proficient) - particularly those below the basic level - lack the foundation for good jobs and full participation in society. (p. 95)

Such knowledge characterizes what a student needs in order to understand the world around them in a logical way guided by the principles of scientific, technological, engineering and mathematical thoughts (Sanders, 2008), the implication being the future economic and social development will increasingly depend on a STEM literate and STEM-capable citizenry.

New Zealand's economic and social wellbeing depends on the productivity and competitiveness of the economy and the ability to make informed decisions as a society. Innovation that leads to increased productivity and solutions to society's most pressing concerns is increasingly being seen around the world as an important way to generate economic growth and improved living standards (Madsen, 2010). A recent report, *A Nation of Curious Minds* (Ministry of Business, Innovation and Employment, 2014) identifies that a creative culture and wide range of skills are needed for innovation, societal advancement and sound environmental stewardship. Internationally, it is recognised that STEM skills underpin the development of new practices and technologies, the application of existing technologies and the development of new, high-value products and services. STEM skills and competencies also underlie growth in many industries and are highly transferable across industries. STEM skills need to be developed as part of the key competencies for life-long learning (New Zealand Curriculum, 2007a) as an individual with higher levels of competency has a much lower likelihood of experiencing both economic and social disadvantage than an individual with lower competency levels (OECD, 2012). Greater community engagement with science and technology could increase the value students and their family or whānau place on the opportunities STEM subjects offer as career pathways (MBIE, 2014). In 2013, NZ Science and Innovation Minister, Steven Joyce and NZ Education Minister, Hekia Parata announced the *Science and Society Project*, a unique joint education-science sector plan to lift engagement and achievement in science, technology, engineering and maths (STEM) across New Zealand to improve the understanding, skills and adoption of science and technology in New Zealand society.

2.12.3 Importance of 'T' in STEM

The recent shifts in workforce patterns and the economic recession have motivated STEM proposals. A significant feature during periods of economic downturn is the promotion of curricular developments in technology education. For example, in Australia, there is a clear correlation among the economic depressions of the 1880s, 1930s and 1980s and significant developments in technology education (Williams, 1996). It is not farfetched that the economic downturn of 2007-2009 is a stimulant to calls for STEM education (Williams, 2011).

Many proposals for a STEM agenda overlook the potential of technology education as a significant component which can integrate cross-disciplinary learning. STEM promotion emphasizes improving student achievements in mathematics and science, and technology educators promote goals such as increasing student motivation, competence and demonstrating the usefulness of mathematics and science (Gattie & Wicklein, 2007). Over the past two decades of educational reform, technology education has shifted its focus on technological design (Sanders, 2009). Technological design could be structured to combine content from science and mathematics, engaging students or teams of students in a technological designing context, which has been considered to be a robust learning environment. Teaching science and mathematics through a technological design context, "formally engages students in this basic human approach to meeting life's challenges and in the process addresses several longstanding issues in science education… and math education" (Haury, 2002, p. 1). The design process compels students to understand the issues, distil the problems, and understand processes that lead to solutions. The use of a design process in technology has been suggested as a way to increase the active participation of students to improve student learning and motivation in science and mathematics (Felix & Harris, 2010), which has been a neglected aspect in many

STEM discussions. The design process offers a sophisticated means of instruction for the school and classroom which can be used as a vehicle to integrate science, mathematics and technology (Sanders, 2009). This approach has important implications for this research as it aims to understand the integration of science, mathematics and technology around a design process to provide an active learning environment for students.

Technology education is characterized as more of an activity than a discrete body of content (Jones, Buntting, & de Vries, 2011; McCormick, 1997). Literature reveals that there is more agreement among technology educators about the activity of technology than the content (Williams, 2000). The traditional focus of technology education being on activity has represented a narrow interpretation of the procedural knowledge. This focus has typically been on the development of the manipulative skills of using tools more effectively and safely. The knowledge in technology could be divided into procedural knowledge which relates to activity and content knowledge (McCormick, Murphy & Hennessey 1994). A realization has developed that there are many significant cognitive skills that are suitable for development in the unique context of technology education, a domain where the theory and practice are to be integrated through a design process (Williams, 2000). There is no other curriculum area which has such potential for bringing in multidisciplinary knowledge and ideas, and testing ideas in a practical way. So it may be appropriate to say that the development of cognitive skills and content knowledge may take place through the procedural knowledge of technology.

Many engineers, scientists or technologists include references to the ‘seamless web’ of the three areas of science, mathematics and technology (Huges, 1986), and it does not differentiate among them. They draw upon the resources of each to complete a given task or to find the solution to a problem. Technology provides the opportunity for this integration to happen through cooperation and collaboration with science and mathematics. The increased motivation that students acquire working on a technological task may be seen by the students as interesting, meaningful and relevant. This could also benefit integration of science and mathematics in a relevant context. Deep understanding is likely to be developed because students are solving authentic problems (Brown, Burton, & de Kleer, 1982). Such understanding is said to be anchored to a personally meaningful context. There is a view held by many (Lai, 2011) that we need to find ways of working in schools and to develop activities to allow students to acquire STEM literacy through the transformation of knowledge from various disciplines for practical application in authentic settings.

2.12.4 Evaluation of STEM Programmes

National programmes have been developed and established in the USA, UK, South Africa, Australia and other countries to coordinate STEM activities. A critical examination of projects has been carried out by various authors (Neville, 2005, 2008; Burrows, 2005) for middle school teachers who wish to implement STEM projects. For example, Learning by Design (Cope & Kalantzis, 2000, 2009) is a project-based inquiry approach (design challenge) to science, aimed at the middle school which claims to develop the skills and understanding needed by the students to undertake the solution of complex, ill-structured problems. These projects generally do not integrate science, technology and mathematics but do bits and pieces of certain concepts from these subjects. Even the sub-title for Learning by Design: "project-based inquiry approach to science aimed at the middle school that works" preferences science over technology. Other programmes like the Project Lead the Way (National Research Council, 2010) use integration to teach particular maths and science content in a technology context. Each of these programmes proposes teaching engineering concepts or engineering design in technology education courses as a vehicle to address the standards for technological literacy (ITEA, 2000/2002). The focus of integration on teaching particular content areas of science and mathematics using engineering design processes without any logical connections challenges the notion of 'interdisciplinary thinking.' The National Science Foundation funded a middle school curriculum, *Problem-Based Inquiry Science* and high school science curricula, *Active Physics*, and *Active Chemistry* that use design challenges and claim to motivate and assess science learning. The 'Materials World' Modules use design to teach specifically about materials science and engineering (Chang, 2009). This is an example where the design process is utilised to teach specific concepts of science so students see the relevance of such concepts.

This approach may make students understand the science and mathematics content the teachers want their students to learn but the ability of the students to consciously make logical connections is questionable. Using the design process as a vehicle to teach science and mathematics might work in the favour of science and mathematics, but students do not experience the process of designing which incorporates numerous ideas and constraints to develop a product. Fortus et al. (2005) found that when students were presented with authentic problems their interest levels in science, technology, engineering and mathematics increased because students saw the need for, or value in, that information. Students involved in working together in cooperative groups on real-world problems are more engaged and interested in STEM subject matter (Sanders, 2008).

Satchwell and Loepp (2002) discussed the issues associated with the design, development and implementation of a standards-based, integrated mathematics, science and technology curriculum (IMaST) for students in grades 6 through 8. Challenges to developing and implementing such an integrated curriculum include (a) the complexity of developing an integrated course consisting of three disciplines, with three separate sets of standards; (b) creating a common planning time for teachers to work together; (c) scheduling; (d) classroom space; (e) teachers' classroom management skills; and (f) teachers' ability to transition to constructivist pedagogy.

According to Pitt (2009), there is little consensus as to what STEM is and how it can be taught in schools. Whether STEM needs to be taught as a discrete subject or an approach to teaching component subjects, what progression is in STEM education, and how STEM learning can be assessed are unresolved issues. This lack of clarity can be seen as an opportunity for research and development to investigate technology classroom teaching and practices which may offer frameworks for meaningful integration.

2.13 Integrative Nature of Technology

There has been some research interest towards technology in school programmes which has included analysis of the relationship between science and technology (Gardner, Penna, & Brass, 1990; Layton, 1993), an exploration of the dimensions of technology (Custer, 1995; Pacey, 1983), and studies of classroom experiences (Davidson, Murphy, Hennessy, & McCormick 1996; Kimbell, Stables, & Green, 1996; McCormick, Murphy, Hennessy, & Davidson, 1996; Northing, 1989; Roden, 1997; Sidawi, 2007; Tala, 2009). LaPorte and Sanders (1993) cited research on hands-on science and the effects of various integrated curricula related to technology, science, and mathematics. The conclusion they reached was primarily that much more research needs to be carried out, especially in the field of technology education, its hands-on approach and its effects on student attributes in an integrated curriculum arrangement.

As discussed earlier in this thesis, a major goal of STEM education is to develop interdisciplinary thinking skills among learners. In his analysis of the term ‘integration’, Pring (1973) concluded that "the very notion of 'integration' incorporates the idea of unity between forms of knowledge and their respective disciplines” (p. 135). Integrative instruction can be a powerful way to present seemingly abstract topics in a practical, application-driven way. The *Principles and Standards for School Mathematics* (2000), issued by the National Council of Teachers of Mathematics, stresses the integration of mathematical concepts and students’ own interests so that they can “connect mathematical concepts to their daily lives, as well as to situations from science, the social sciences, medicine and commerce” (p. 147). Helping students to make such connections among the various disciplines is a topic that has been central to recent educational reform agendas (Lappan, Fey, Fitzgerald, Friel, & Phillips, 2002).

A powerful political partnership which involves the AAAS, National Academy of Sciences, National Science Teachers Association, National Academy of Engineering, and the Achieve organization in the publication titled *Next Generation Science Standards* (NGSS, 2012) re-validates the integrative STEM approach through statements such as:

> What is different in the *Next Generation Science Standards* (NGSS) is a commitment to fully integrating engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels, and by according core ideas of

> engineering and technology the same status as core ideas in the other major science disciplines. (NGSS, 2012, p. 1)

The NGSS (2012) also includes the following rationale for promoting and validating integrative STEM education through engineering and technology: "From a practical standpoint the Framework notes that engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge in different contexts" (p. 4).

That science education scholars have been investigating integrative STEM instructional approaches for the past two decades further adds to the appropriateness of this approach (e.g., Cajas, 2001; Crismond, 2001; Edelson, 2001; Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2004; Fortus, Dershimer, Krajcik, Marx & Mamlok-Naaman, 2005; Kolodner, 2002; Roth, 1991, 1992, 2001; Schauble, Klofer, & Raghavan, 1991; Seiler, Tobin, & Sokolic, 2001; Sidawi, 2009).

The National Academy of Engineering (NAE) has administered several projects which promoted integrated approaches to STEM education as a means to introduce engineering content into K-12 schools (e.g., Committee on Standards for K-12 Engineering Education, 2010; Katehi, Pearson, & Feder, 2009). Also, the NAE's project (2014), *Toward Integrated STEM Education: Developing a Research Agenda*, "aims to develop a strategic research agenda for determining the approaches and conditions most likely to lead to positive outcomes of iSTEM" (p. 2).

In mathematics education, a growing number of researchers have also begun to investigate the teaching and learning of mathematical concepts in K-12 technology and engineering design contexts (e.g., Burghardt, Hecht, Russo, Lauckhardt, & Hacker, 2010; Moore, 2012; Nathan, Phelps, & Atwood, 2011; Nathan & Wagner, 2011; Norton, 2007; Stone, Alfeld & Pearson, 2008).

Students working collaboratively on well-defined integrated projects could demonstrate increased use of knowledge in different situations (across the subjects) and improved problem solving and social outcomes (Turner, 1995;

Ziman, 2000). Some researchers claim that integrated instruction increases student interest and curiosity (Brusic, 1991; Ingram, 1996), engagement and problem-solving skills (Loepp, 1999); and skills in certain subjects (Clayton, 1989; Cordogan, 2001; Dugger & Johnson, 1992; Fisher, 2001; Gattie & Wicklein, 2007). There has been reasonable evidence to assume that mathematics achievement has improved when it is taught in a technological context (Norton, 2008). Therefore, for developing interdisciplinary thinkers with a range of cognitive skills, integrated instruction seems to be a useful approach.

The procedural aspect of technology naturally integrates cross-disciplinary knowledge. There are many significant cognitive skills which are important for students to develop, and which are suitable to be developed in the unique context of technology education (Williams, 2011). Children often learn technological skills in classrooms by engaging with materials and building structures or devices. Sometimes, they are given a design brief that sets out criteria to be fulfilled, or asked to construct models to solve ill-defined problems. Framing these types of situations may involve science, mathematics concepts or technological procedures to be recognized during the design process.

While technology as a subject for all students makes it more visible in the curriculum, many have noted the close relationship that exists between science and technology which could be developed for student engagement with science and technology in their general education (Barlex & Pitt, 2000; Bencze, 2001; Hadjilouca, Constantinou, & Papadouris, 2011; Lewis, Barlex, & Chapman, 2007; Petrina, 1998; Sidawi, 2007). Fensham and Gardner (1994) argue that science and technology should be taught in partnership rather than teaching technology as applied science on one hand or as separate subjects. On a much broader basis, Petrina (1998) and Tala (2009) advocate a view of technology as multi-disciplinary, that curriculum development should draw on a range of knowledge domains rather than searching for a mono-disciplinary identity of the subject. Also for the teaching of mathematics, several studies identify the potential for integration with technology (Norton & Ritchie, 2009). Technology is seen as providing rich opportunities for learning and applying mathematics in authentic and relevant contexts, as well as developing more positive attitudes towards the value of the subject (Norton & Ritchie, 2009). Hence, technology can be seen as representing a domain of knowledge in itself, while on the other hand technology as a field of activity makes use of and combines knowledge from a range of different areas in order to fulfil specific purposes (de Vries, 2011). The knowledge component of technology in the school curriculum remains contested terrain (e.g., Jones, Buntting, & de Vries, 2011). From this perspective, it can be said that technology education provides a platform for integrated instruction through application of knowledge from science, mathematics and technology.

There is optimism for improving science and mathematics teaching through integration with technology in a design context (Furner & Kumar, 2007). The integration of mathematics and science should be carried out wherever possible in the curriculum. The critical role of mathematics assisting in understanding the relationships between principle scientific concepts within the context of technology cannot be underestimated. In such a context, student success may depend on the degree to which mathematics and science are integrated in order to motivate and engage students in meaningful learning.

This research aims to provide a better understanding of the processes surrounding the design and delivery of instruction which integrates science, mathematics and technology, and the student response to such integration in a technology classroom. This may provide technology teachers with a foundation for planning lessons and building units that utilize 'cross disciplinary' integrated instructional teaching environments. In an era dominated by science, mathematics and technology (Furner & Kumar, 2007), it is essential that links be drawn to science and mathematics in a technological design context, and to do so technology teachers must be equipped with the necessary knowledge and skills.

2.13.1 STM Connections

Examining the learning standards developed by professional associations of science, mathematics and technology education in the United States, may lead to the conclusion that there exists a mutual relationship among the three disciplines. Within the *Principles and Standards for School Mathematics* (NCTM, 2000) set for pre-kindergarten through twelfth grade standards in the US, the Connection standard reads that students will recognize and apply mathematical concepts in context outside mathematics, and the Problem Solving standards reads that students will solve problems that arise in mathematics and in other contexts. After a critical analysis of both *Principles and Standards for School Mathematics* (NCTM, 2000) and *Standards for Technological Literacy* documents (ITEA, 2000), both disciplines identify the scope or purpose of technology in mathematics as that of use. Similarly, there lies a potential for using connections between technology and science education to improve students' scientific and technological literacy leading to instilling a sound understanding of content in both areas. Science education has deep rooted historical ties with technology education and a strong parallel relationship in both pedagogical and content practices (Wells, 2010). There appears to be room for these disciplines as specified in the New Zealand technology standards to collaborate on developing effective integrative practices (Compton, 2004).

Implicit in technology education is the emphasis on real world authentic problem solving incorporating both mathematical and scientific principles across these domains which remain the fundamental rationale for integrative STM education. It seems that science, mathematics and technology trajectories are well aligned to mutually benefit from an integrative approach to learning and teaching (ITEA 2000/2002; Merrill, Reese, & Daugherty, 2010). This research will focus on a technological design context and how students bring in knowledge (from various disciplines) and skills to solve a technological design problem.

2.13.2 Why STM is Preferred over STEM

Science, Technology, Engineering and Mathematics are each based on different epistemological assumptions. Science seeks to develop an understanding of the world through testing hypotheses and to understand a set of defined beliefs about how the natural environment works. Mathematics as a discipline helps students to analyse, reason, and communicate ideas effectively as they pose, formulate, solve, and interpret solutions to mathematical problems in a variety of situations. Engineering deals with the understanding of how technologies are developed via the engineering design process using project-based lessons in a manner that integrates lessons across multiple subjects, while doing technology develops new knowledge created through becoming involved in a design process which has an element of uncertainty to it. The nature of the problem in technology sets the design brief and a critical analysis of the problem becomes an important part of the design process as this defines the body of relevant knowledge needed to progress towards the optimal solution (Williams, 2011).

The nature of problem solving is different in engineering and technology. In engineering, the context determines the relevant knowledge needed to proceed with the problem, thus making it independent of the nature of the problem (Williams, 2011). But it cannot be presumed that technology is decontextualized, rather it is less associated with a defined body of knowledge than engineering. An ill-defined context in technology allows students to explore their creativity and also to define relevant knowledge as they start designing. Although technology and engineering are different, the argument for integration is that these epistemological positions could be complementary (Williams, 2011). Williams indicates that STM would be more appropriate because engineering is actually a sub-set of the broad area of technology. Engineering is also not a school subject in the national curriculum of New Zealand. Thus, the major focus in this study will be on technology education to investigate how students integrate knowledge to solve a real world problem and enhance their creativity and problem-solving abilities.

2.13.3 Integration of Science, Mathematics and Technology

Integrating mathematics and science in schools has become a central issue of many US organizations as indicated by the School Science and Mathematics Association (SSMA), the National Council of Teachers of Mathematics (NCTM), the American Association for the Advancement of Science (AAAS), and the National Research Council (NRC). Not only the US, but many other organisations around the world (NRC, 1996) strongly support the integration of maths and science, which is reflected in national standards documents (Furner & Kumar, 2007; NCTM standards, 1989/2000). NCTM (2000) makes Connections one of its process standards and advocates the integrating of subjects like mathematics and science. Technology education is a capable partner in a curriculum that emphasises the application of science and mathematics. "Technology education has, within its content and methodology, a prime vehicle through which the subjects of the school are brought together for the purpose of meaning, understanding, and relevance on the part of the learner" (Maley, 1985, p. 7).

Beane (1991) characterized the true nature of integration as an activity which is experience oriented. In recognition of the way students integrated knowledge "into their own systems of meaning" (p. 12), such a process begins with a constructivist's point of view. Beane advocates that integrative processes be child centred, relating to his or her concerns and questions about self and society (Beane, 1991; Tyler, 1949). Technology education should be a key partner in bringing activity and experience-oriented instruction to the student through the integration of science, mathematics and technology because such an approach will help bridge the gap between classroom teaching and authentic learning contexts (Berlin & White, 1992; Furner & Kumar, 2007).

Jacobs (1989) noted that the focus of integration should not be providing factual knowledge, but to provide instruction fostering general understanding, learning skills, and affective skills. Integration of science, mathematics and technology could help to provide relevance of content in the minds of students. Integration can provide sensible curriculum organization and to some extent, instructional scheduling, thus deliberately connecting disciplines and scheduling instruction to make the content relevant for the students.

2.13.4 Outcomes of Integration

Research indicates that using an integrated curriculum provides opportunities for relevant, less fragmented, and stimulating experiences for learners (Frykholm & Glasson, 2005; Jacobs, 1989; Koirala & Bowman, 2003). Integrated teaching can be said to be a way to capture student interest and to develop knowledge (Repko, 2008). Integrated teaching plays an important role of not only reaching students during their initial learning stages but influencing the teaching of subjects, and through the cooperative involvement of both students and teachers planning and learning together to modify instruction (Antonellis & James, 1973; Jacobs, 1989).

Often students cannot solve problems because they do not understand the context in which the problems are embedded (Frykholm & Glasson, 2005). This separation of content from a context can be viewed as a jigsaw puzzle which does not suggest a clear picture of the relation of the content with the context. However, if done effectively, integration of maths, science and technology could bring together overlapping concepts and principles in a meaningful way to enrich the learning context in technology. Learning situated in such an enriched authentic task or context often leads to stimulating learning experiences (Repko, 2008).

Subjects such as mathematics, science and technology are generally taught separately in school by different teachers who often focus on teaching the obligatory subject matter and have little knowledge about other subjects not within their area of expertise. Barak and Pearlman-Avnion (1999) presented an attempt to integrate the teaching of science and technology into a context about sound and sound systems from scientific and technological perspectives; Barak and Raz (2000) reported on the outcomes of a programme aimed at teaching science and technology, including electronic remote control, around the design and construction of huge hot air balloons. In both studies, there was a disconnection between the science and technology teachers prior to enrolling into the programmes; the science teacher knew very little about technology or the technology curriculum, and vice versa. In addition, mathematics teachers know very little about what students learn in science and technology. From an integration perspective, bridging this gap has remained an important issue in teaching science, maths and technology in primary and high schools because educators are understanding the need to impart to students a broad view of the relationships between science, technology engineering and mathematics (STEM) (Bybee, 2010; Sanders, 2009).

Pyke and Lynch (2005) found in a study of mathematics and science teachers' doing preparation for the National Board for Professional Teaching Standards (NBPTS) certification enrolled in an integrated preparation course clearly indicated that an integrated approach produced higher scores and higher passing rates for most of the respondents. The results indicated that the collaborative preparation was highly valued for motivational and instrumental support.

Also, the involvement of students in an integrated science and maths unit has led to the increase in their motivation levels (Friend, 1985; Wolfe, 1990) and increased student achievement in both disciplines (McBride & Silverman, 1991). This relates directly to the constructivist approach of hands-on minds-on learning where any prior knowledge is used by learners to interpret observations; meaning is constructed by individuals in a process of adding to or modifying their existing ideas (Driver, 1983; Osborne & Freyberg, 1985; Scott, 1987). The implications of such a view are that teachers then need to provide experiences which challenge the learners' current understanding in order to help them restructure their ideas (Driver & Oldham, 1986). The implications of such a view are that the teachers need to discover the student's ideas in order to take them into account while teaching. Much recent research in science education (Keogh & Naylor, 1996) has been concerned with investigating the ideas which learners typically hold in order to inform teaching but the practicality of such an approach is again vague when it comes to technology, because in technology the context defines the content. This provides a motivation to research a technology classroom in its natural state to observe how the understanding of the students transforms while designing and making.

Greene (1991) found profound student interest and increased achievement scores on the *National Assessment of Educational Progress* for California students enrolled in year-long thematic units. Vars (1991) also reported higher standardized achievement scores associated with integrated instruction. After a meta-analysis of 30 quantitative studies on the effectiveness of integrated instruction on student achievement was carried out by Hartzler (2000), she concluded that (a) students in various types of integrative/interdisciplinary programmes performed as well or better on standardized achievement tests than students enrolled in the usual separate subjects; (b) students in integrated curricular programmes consistently out-performed students in traditional classes on national standardized tests, in-state-wide testing programmes and on programme-developed assessments; (c) integrated curriculum is a viable alternative to traditional subject-centred programmes without fear of student failure or declining standardized test scores; (d) integrated curricular programmes were successful in all four of the major academic areas: Language Arts, Maths, Social Studies, and Science and at all grade levels showed the most promise; and (e) students from all socio-economic levels benefited from integrated curricular programmes.

Although some research and resources are available to support the integration of mathematics and science, in many classrooms they are not actively used (Furner & Kumar, 2007). This could be because teachers do not know how. One of the ways of doing so is through the active engagement of students in the process of technology in schools which has the potential to integrate science and mathematics; technology provides a context through which science and mathematics knowledge naturally integrates.

When students in a technology classroom are working on a range of different design projects, the application of knowledge from other subject areas arises incidentally (Williams, 2011). The promotion of such cross-curricular links is beneficial to the student and it will be a major aspect of this research. From a research study in Western Australian middle schools (Venville, Wallace, Rennie & Malone, 1998), teachers noted several advantages of integration for their students. The contextualized nature of problem solving was regarded as highly beneficial for integration, especially by mathematics teachers. Some teachers noticed their students better understood mathematics and science concepts when they applied their knowledge to a practical task in technology and conversely, the technology products were said to be of better quality when the students were able to use mathematics and science skills and knowledge to improve their designs. This is supported by Roth (1998) who argued that the study of technology and science are mutually supportive practices since engaging in technology-based activities overlaps with the practices of science. It is the extent of overlap between science and technology which determines the engagement of students with the practices of science and technology simultaneously (McCormick, 2004).

A number of studies have concluded that increased student interest and motivation resulted from an interdisciplinary approach (Gilbert, 2007). The following sections will highlight the potential of integration through technology.

The next sections will discuss the various problems with integrating science and mathematics in the design process. These findings from the literature help understand the integration of science, mathematics and technology in a design context.

2.13.5 Problems with Integration

Integrating science, mathematics and technology through technological design activity can lead to conceptual learning through the procedure, but few teachers are expert at facilitating its enactment. Sidawi (2009) examined the literature on studies of science teachers using technology to teach science. The logic of most of these attempts was to solve a technological problem using the design process that can provide a meaningful context to apply knowledge leading to better understanding of science. Despite the apparent logic of the idea, Sidawi found the integrative approaches were not successful because:

> • teachers did not have a grasp of the complex relationship between science and technology and assumed that technology was simply applied science;
>
> • the students were not able to transfer their learning of science to designing technology; and
>
> • teachers did not have a deep understanding of the design process and tried to teach it as a linear, context-free process without regard to the context of the problem. (p. 269)

In a three year study, Koirala and Bowman (2003) focused on pre-service teachers who completed an integrated course on mathematics and science methods. Based on analyses of classroom observations, teacher reflections, and student interviews, it was evident that the middle-level pre-service teachers appreciated the emphasis on integration and acquired a better understanding of integration, yet recognized the difficulties associated with carrying out integration, namely that it is difficult to plan, design and implement integrated STEM units.

To gain a better understanding of teachers' beliefs about, perceptions of, and classroom practices using STEM integration, a multi-case study (2009–2010) was conducted with three middle school teachers by Wang et al. (2011). The mathematics teacher believed that STEM integration may only help parts of his teaching, if a STEM project did not address mathematics standards. He believed STEM integration could increase his students' interest and motivation in learning mathematics, but it did not help him to teach his subject in a more effective way. The willingness to take a risk was also a vital requisite as teachers' may have to depart from their established practices over long teaching careers to incorporate STEM lessons.

Even in science classes where teachers encourage design activity, not all students are able to connect their design experiences to conceptual science topics (Ryan &

Kolodner, 2004). Also, when it comes to a whole class, a group of able students may be more knowledgeable compared to other students. Some students need more time and opportunities experiencing and analysing a concept, and attempting its application, some need more variation across those opportunities; and some need more specific guidance.

McCormick and Evans (1998) asserted that students' fragile and varied understanding in mathematics was frequently not sufficient to make sense of the mathematical concepts being introduced in an authentic context. An independent report on the New Basics (a large-scale intervention of an integrated programme in primary schools in Australia) by Cooper, Nuyen and Baturo (2003) suggests that without the curriculum of mathematics in parallel with integration, student learning may have been minimal for many students during integration. This may give rise to a situation where students may complete the designing of their artefact for the sake of completion without gaining relevant knowledge from science, mathematics and technology.

Another problem during integration comes with the change of role of science and mathematics in a technological design context. This occurs because the context radically changes the way knowledge is represented. Scientific concepts (essential science and maths) need to be defined in a technological context for students to expand their STM knowledge and skill base. This knowledge needs to be contextualised and made understandable to the students so that it can be used within a design task. In analysing the scientific demands, it is necessary to identify what these are: for example, the knowledge of tension, stress, bending, etc. has to be transformed into a meaningful understanding within a design context where students are building a bridge, tower, building, etc. It is important to consider the context in which such understanding will be achieved. One of the essential problems is the change of role of science and mathematics acting as support subjects for technology and having to fulfil its own epistemological role of autonomous subjects with aims, objectives, theories, principles and hypothesis. This gives rise to some practical difficulties in integrating these subjects.

For example, an initial understanding about forces, stability and mathematical tools to plot graphs, tables and calculating areas is essential for students in designing a structure. The form of scientific and mathematical understanding and knowledge developed for application in a technological context may not be the same as in the traditional approach to learning in these subjects.

The problem of timing and sequencing can arise during a technological design process as there is no single mandatory body of knowledge for science and mathematics as applied to design activities. The need for specific knowledge may arise in technology before it is covered in a maths or science classroom. Interdisciplinary knowledge from science and mathematics can be taught on a need-to-know basis in a technology classroom. If students are given information when they realize they need it, their level of retention is higher and they will learn more efficiently (Williams, 2000). This approach provides an immediate purpose for learning and the application of scientific and mathematical knowledge. This form of integration has been considered powerful and has the theoretical support of those who value situated learning (e.g., Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991).

The next section will discuss the objective of the constructivist views of learning which will help to construct a conceptual framework for this study at a later stage.

2.14 Constructivist Views of Learning

Technology educators need to focus on learning strategies which develop a critical understanding of the connections between key concepts among various domains in a technological design context in order to promote active engagement and participation (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). One of the ways to develop such a strategy could be to conduct a detailed investigation of a technology classroom working on a technological design context to actively solve problems, through a constructivist approach, trying to create their own meaning in pursuit of optimal solutions through social interaction, collaboration and co-operation.

Constructivist views of knowledge and learning mark a shift in focus from the object of experience, or the known, towards the subject of experience or the knower (Campbell, 2002). These views hold that knowledge is constructed internally by the individual and socially during interactions with others. Constructivist theories come in many forms: cognitive constructivism, radical constructivism, social constructivism, and sociocultural theory (social accounts of constructivism). Elaborations of these theories are open to divergent interpretations, the use of concepts varies (Campbell, 2002) and it is not easy to make a clear distinction between the various theoretical positions. The readers of constructivist literature determine which epistemological direction is to be pursued for their study (Phillips, 1995). This is discussed in the following sections.

2.14.1 Subject-Centred versus Social Accounts of Constructivism

Constructivist theories can be positioned on a continuum with subject-centred accounts at the one end and social accounts at the other (Davis & Dennis, 2002). The distinction has its origin in the different epistemological claims about the nature of knowledge. Subject-centred accounts stress that individuals construct their own knowledge and understanding; they include accounts such as cognitive theories and radical constructivism. Social accounts of constructivism situate the process of learning in the social domain and consider knowledge as something that emerges out of social interaction. Learning from social accounts of constructivism is viewed as inherently social; people construct "shared versions of knowledge" (Burr, 2003) when they try to make sense of their mutual experiences and practices. Social accounts include theoretical positions like social constructivism and sociocultural theory.

2.14.1.1 Subject-centred constructivism

Subject-centred constructivism states that the mind does not passively accept sensory impressions; rather the mind actively imposes an interpretive framework on sense data. Reality, in other words, is constructed (Driscoll, 1994). Many cognitive theories (except behaviourism), which are inherently subject-centred, entail some form of constructivism to the extent that the cognitive structures are typically viewed as individually constructed in a process of interpreting experiences in particular contexts (Palincsar, 1998). The challenge of teaching, from this point of view, is to present the learning material to the students in a way which allows effective and accurate constructions of internal representations. It means that the teacher introduces the subject matter in an accessible manner that closely matches the cognitive abilities of the individual student, taking into account how people acquire and organize information cognitively. The teacher presents the knowledge in parts that are easily understood, points out connections and explains what is difficult to understand. Reiteration, multiple representations and referring to existing knowledge are seen as effective strategies for knowledge acquisition.

Radical constructivism is based on both the first and second of von Glasersfeld's principles, the second of which states that "the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality" (Von Glasersfeld, 1989, p. 182). Consequently, "from an explorer who is condemned to seek 'structural properties' of an inaccessible reality, the experiencing organism now turns into a builder of cognitive structures intended to solve such problems as the organism perceives or conceives" (Von Glasersfeld, 1989, p. 50). This can be elaborated in the context of student thinking and learning. When a student tackles a real world problem, he/she does not know what the solution of that problem is. But they do create an image of what the problem will look like when they get immersed in the pursuit of that solution which has yet to be discovered. The learner then generates cognitive schemas to guide actions and represent their experiences. Those schemas that are relevant are tentatively adopted and retained as a guide for action. Schemas evolve, and through adaptation come to better fit the subject's experienced world. Radical constructivism refers to the work of Piaget who sees learning as a process of adapting one's internal belief system triggered by individual experiences.

2.14.1.2 Social accounts of constructivism

Social accounts of constructivism consider experience rather than an objective source outside these experiences as the reference for knowledge construction. However, social accounts do not place the individual apart from the social world as radical constructivism does. The subjectivity of the individual and the objectivity of the surrounding social and cultural context exist in relation to one another (Davis & Sumara, 2006). Properties of social accounts like language contribute to the construction of knowledge. Social accounts of constructivism include theoretical positions like social constructivism and sociocultural theory. Social constructivist learning theory considers human learning is not a solitary activity by individuals who make sense of their world. Knowledge is temporary, developmental, non-objective, internally constructed and socially and culturally mediated (Fosnot, 1996). Thus social constructivism stresses the social dimension of cognition and the role that language plays in promoting learning in that environment (Palincsar, 1998).

Sociocultural theory sees human learning through the manner in which the social and cultural world co-determine the way in which people approach learning in various settings, inside and outside formal institutions (Bliss & Säljö, 1999). Thinking is culturally mediated by artefacts such as signs and tools, it is founded in purposive activity and it develops historically (Packer & Goicoechea, 2000; Scribner, 1997). The defining concepts of sociocultural theory – human action, the use of tools and mediation – can be traced back to the work of Vygotsky (Lemke, 1995). All activities contain different artefacts, and these artefacts or tools embody a certain history and culture (Vygotsky, 1986). In sociocultural theory, artefacts play an essential role in shaping action; they mediate human action (Wertsch, del Rio, & Alvarez, 1995). Every mediating system has distinct features that shape the nature of communication and learning that takes place in that environment. This means that human experience is shaped by the artefacts that are used (Nardi, 1996).

2.14.2 Taking a Position

This research will draw broadly from social-constructivism which assumes that learners construct knowledge through social interaction and that the nature of these interactions affect collaboration and learning, and also from the socio-cultural perspective which sees context and cultural practices as fundamental units (Rogoff & Lave, 1984). This approach allows this study to focus on appropriate frames to understand the integration of science, mathematics and technology in a social learning environment.

With regard to this study, a position is not taken from a relativist perspective which suggests that essential properties of an object of the world are relative to their description (Moser, 1993) or those properties that are part of the object's definition. This study acknowledges that human action is based on cultural belief systems that are socially constructed and that a reality lies outside these experiences or discourses. However, the perceptions and actions of people do not mirror reality, they do refer to the world in some way. The perceptions are not independent of the surroundings, and produced entirely through symbolic systems such as language (Burr, 2003).

The next section will examine the development of an argument for this perspective by discussing a technology classroom and the practices enacted by the various actors in that environment.

2.15 Focus on a Technology Classroom

Collaborative learning in a technology classroom could be viewed from both a social-constructivist and a socio-cultural perspective that stresses the "interdependence of social and individual processes in the co-construction of knowledge" (Palincsar, 1998, p. 347). The conceptual framework for this study, which will frame the research analysis of the integration of science, mathematics and technology. But first, the subsequent sections will discuss how the construction of knowledge emerges on the social level first, while recognizing the role of the individual in social construction. This will assist in explicating particular relationships observed during classroom technological activity. The various forms of technological knowledge will then be discussed with a focus on the construction of knowledge on the social level in technology. The discussion starts by examining the nature and culture of technology classrooms with their specific and shared practices.

2.15.1 Classroom Community

Culture is widely understood as a set of shared values, beliefs, customs, practices, principles and routines that underpin the behaviour of an organisation and its members, usually cultivated steadily over a long period (Arnott, 2000; McDermott & O'Dell, 2001). Specific cultural practices are unique to the community and they help constitute it as a community (Lemke, 1995). The way knowledge is generated in technology can be characterised by the ways the community shares the values and practices (technological practices) associated with their culture. In technological communities, these ways are oriented towards the development of systems which solve problems, extend human capabilities and satisfy human needs (ITEA, 1996; 2000). In the context of this study, a technology classroom can be viewed as a community of learners and experts who share their values and practices in certain ways to generate knowledge by designing and problem solving.

The technology classroom can be viewed as a group of humans carrying out specific and shared practices associated with designing despite their differences in interpretations of the confronted problems. Generic processes associated with technological activity such as investigating, planning, modelling and making, and evaluating are called 'aspects' (Williams, 2011) which students encounter while designing and making in a technology classroom. Students interact with each other, and with the teacher, to generate knowledge mostly by designing and problem solving while making technological products. This scenario can be classified as a classroom community of learners comprising the students and the teacher (Brown & Campione, 1994; Rogoff, 1994) in which knowledge is co-constructed (Barnes, 1976). Students engage in actions which are unique to the practices of technology and in the process they negotiate ways of "being a person in that context" (Wenger 1998, p. 149). Such practices of the classroom community (i.e., technology classroom) require that members have ways of engaging with one another and acknowledging each other as participants. This research will examine the technology classroom as an educational community acting through hands-on activities and dialogue, with the interaction between the various actors (students and teachers) in a classroom reflecting cultural values and the social practices of the community.

Several elements contained within these discussions can be recognised within the New Zealand technology curriculum, specifically within the *Technological Knowledge* strand of the New Zealand technology curriculum. In this strand, students are encouraged to investigate technological products, their materials and material properties, along with modelling and technological systems. The third strand named the *Nature of Technology* frequently overlaps with this and aims to guide students in considering the impact and influence society has on technological developments. The following section will discuss the construction of knowledge on a social level in technology education which would justify the conceptual framework for this study.

2.15.2 Knowledge Construction on a Social Level

The relationship between technological knowledge and technological activities is of interest to this research in order to help develop a picture of how integration could be facilitated in future technology classrooms. Thus technology education in schools can provide students the opportunity to identify and use knowledge from various domains through the practical nature of technology.

The knowledge of technological practice to be gained in technology is achieved through social interaction and collaboration (Rowell, 2004). The knowledge of practice in an active community like a technology classroom is mediated by the use of tools, resources and language. Thus a community exists in a technology classroom and this perspective gives recognition to the practices of communities. Such communities engage in technological activities that are characterized by the ways in which they interact among themselves and with the materials, tools and resources through collaboration.

The discursive practices of a community constitute the ways in which members approach action. Discourses around design and designed systems in technological communities address the decisions made by people in using materials and building devices. Thus trade-offs which may arise due to either physical or social constraints made by students and the teacher keeping in mind an anticipation of failure, assessing the risk and through co-operation and collaboration, considered to be the integral strands of technological discourse. In summary, there exists a community of experts and learners in a technology classroom based upon their experience and decisions made to approach action mediated through tools, resources and language.

So, if technology education is regarded as a human practice and technological activity is viewed as a social construction, then this study should be oriented towards understanding the social-constructivist and socio-cultural ways of integration of science, mathematics and technology when students work on a technological design context. Communication, collaboration and the quality of social interactions will be investigated in detail to describe how integration of cross-disciplinary knowledge takes place while designing and making. Their engagement in the design process and solving problems in a design context provides a platform for the students to integrate thoughts and develop appropriate actions through communication and collaboration.

Several studies (Barron, 2003) within social-constructivism have examined what kind of communication contributes to the co-construction of knowledge during collaborative learning in practice. According to Barron (2003), the quality of such social interaction has important implications for learning. This study will adopt a framework, drawing on both social constructivism and a socio-cultural perspective to frame the analysis of this study which will be discussed in more detail in the subsequent sections.

2.16 Conceptual Framework

A conceptual framework applies part of theory or an idea of a theory to investigate certain phenomenon in the research work. Existing formal theories with coherent explanations of certain phenomena will help develop a structure that will guide the research by devising an argument for investigation on the basis of which judgments can be made regarding integration

This research will draw broadly from both social-constructivist and socio-cultural theories that assume that learners construct knowledge through social interaction and that the nature of these interactions affects collaboration and learning. This framework will provide a structure to explain how students engage in a technology classroom to integrate science, mathematics and technology. This framework allows the researcher to adopt an appropriate focus on the collected data to fulfil the objectives of this research. The subsequent sections will explore the literature in the areas of both social constructivism and socio-cultural theories to provide the necessary background information and rationale for the study.

2.3.2.1 Social Constructivism

Social constructionism originated as an attempt to come to terms with the nature of reality. The emergence of social constructivism took place some thirty years ago, has its origins in sociology and has been associated with the post-modern era in qualitative research. Social constructivism emphasizes the importance of context and culture in understanding what occurs in society and constructing knowledge based on this understanding (Derry, 1999; McMahon, 1997). The aim of the next section is to familiarize the reader with the assumptions of social constructivism.

2.16.1 Assumptions of Social Constructivism

Social constructivism is based on specific assumptions about reality, knowledge, and learning. To understand and apply models of instruction that are rooted in the perspectives of social constructivists, it is important to know the premises that underlie them.

Reality: Social constructivists believe that reality is constructed through human activity and engagement with the environment. Members of a society, together, invent the properties of the world (Kukla, 2000). In Social Constructivism, reality cannot be discovered: it does not exist prior to its social invention.

Knowledge: In Social constructivism, knowledge is a human product, and is socially and culturally constructed (Ernest, 1999; Gredler, 1997; Prawat & Floden, 1994). Individuals create meaning through their interactions with each other and with the environment they live in.

Learning: In Social constructivism, learning is viewed to be a social process which does not take place only within an individual, nor is it a passive development of behaviours that are shaped by external forces (McMahon, 1997). Meaningful learning occurs when individuals are engaged in social activities.

Social accounts of constructivism consider knowledge as something that emerges out of social interaction or social activity and situate the process of learning in the social domain. People construct "shared versions of knowledge" (Burr, 2003, p. 21) when they try to make sense of their mutual experiences. Such social accounts include theoretical positions like social constructivism and sociocultural theory. The following sections will discuss social constructivism in detail and will also highlight how this framework would allow this study to answer its research questions.

2.16.2 Social-Constructivist Perspective

Social-constructivist theories can be positioned on both sides of the realist-idealist continuum, but most theories firmly lean towards the idealist end. Some social-constructivist theories maintain some concept of reality that exists outside the discourse (Burr, 2003). The idealist accounts state that learners cannot know reality in itself, only in so far as it is given in consciousness, experience, language, or practice (Collier, 1998). Zuriff (1998) made a distinction between empirical and metaphysical social constructivism, both of which can be situated at the two ends of the Realist-Idealist continuum. Empirical social constructivism distinguishes the natural world from the constructed world and admits that constructions are descriptions of the natural world. Metaphysical social constructivism rejects the view that the natural world consists of an external objective reality, independent of the human mind (Zuriff, 1998). This study cannot isolate the human mind from the natural world and considers both to be part of a social context.

A social account of learning considers prior knowledge gained through experiences to ascertain knowledge construction in a social context. However, social accounts do not see the individual as distinct from the social context as does radical constructivism which represents a private, cognitive and constructive approach to the acquisition of knowledge. According to Davis and Sumara (2002), the subjectivity of the individual and the objectivity of the surrounding social and cultural context exist in relation to one another. This study assumes that sense-making is a social process of people who interpret mutual experiences. Therefore, the units of analysis to investigate integration of science, mathematics and technology in the classroom will include the social activity, the mutual environment that shapes thinking, the interactions between people, and a combination of these units.

In a technology classroom where a student centred learning environment is being enacted, the focus should be on the communicative nature and social dialogue that enable knowledge to be constructed, which will in turn aid an understanding of the process of integration of science, mathematics and technology. Social constructionism places the social dimension of knowledge construction prior to the individual's and acknowledges the constructive power of language (Burr, 2003; Gergen, 1995). Knowledge is considered to be constructed on a social level through interaction and internalised on an individual level. The emphasis is on the social dimension of cognition and the role that language production plays in promoting learning and generating knowledge (Palincsar, 1998). Language plays a very important role as a tool in the construction of cognition in a collaborative and socially co-operative manner. This will be discussed in more detail at a later stage.

It is appropriate to adopt this framework which will help to analyse the classroom activities based on insights, perceptions, language, beliefs, desires and the experience of the students and the teacher with their practices in a broader sense. The social constructivist framework allows the researcher to focus on the classroom/workshop which shapes and promotes social interaction and collaborations that encourage thinking processes to solve the problem in hand. So far what social constructivism means and the relevance of this perspective for the study has been discussed and defined. The next section will focus on the socio-cultural theoretical approach and will identify ways this perspective can help the researcher to answer the research questions.

2.16.4 Socio-Cultural Theoretical Approach

Sociocultural approaches to learning and development were first applied by Vygotsky and his collaborators in Russia in the 1920s and 1930s. Vygotsky's sociocultural theory of learning describes learning as a social process where social interaction plays a fundamental role in the development of cognition. From that perspective, education and cognitive development are seen as cultural processes, whereby knowledge is not only possessed individually but shared amongst members of communities; and understandings are constructed by people jointly, through their involvement in events which are shaped by cultural and historical factors (Vygotsky, 1978). Vygotsky believed everything is learned on two levels, firstly through interaction with others (interpsychological), and then integrated into the individual's mental structure (intrapsychological).

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher

> functions originate as actual relationships between individuals. (Vygotsky, 1978, p. 57)

An argument put forward by Vygotsky was that a child's development cannot be understood by a study of the individual only, but should also be examined in the external social world in which that individual life has developed. This development happens through continuous participation in activities that require communicative and cognitive functions, children are drawn into the use of these functions in ways that nurture and 'scaffold' them (p. 6-7). Vygotsky (1978) believes that scaffolding also occurs, but with someone with more knowledge helping and assisting those with less. As the student internalizes and understands, then less help is given until the student is able to act on his or her own. In a review of the literature, Kublin et al. (1989) succinctly state that "Vygotsky (1934/1986) described learning as being embedded within social events and occurring as a child interacts with people, objects, and events in the environment" (p. 287). Thus an overarching focus of this study will be the interdependence of social and individual processes in the co-construction of knowledge through continuous participation of the students among themselves, teacher, materials and other resources while designing and making.

This study will also recognize the construction of new understanding as a combination of prior learning through experience and contextual knowledge related to the context. This knowledge may be technological, scientific, and mathematical or from any domain which may be interpreted to form conceptions and misconceptions by the individual. This knowledge can be fostered in a social context when shared among students in the classroom, creating a community of learners who, together, build, manipulate and develop their understanding and knowledge to enrich mutual learning experiences. Technology classrooms can be viewed from a sociocultural perspective which can be compared to open communities where all ideas, knowledge and practices, irrespective of their origin, are open to be challenged by the students.

According to Tharp and Gallimore (1988), the sociocultural perspective has profound implications for teaching, schooling, and education. The concept that human activities take place in cultural contexts (technology classroom), and are mediated by language, materials, mechanical tools and other symbol systems, which can be best understood when investigated in their historical development, i.e. the development associated with technological development over time. Cultural context is a notion of community of practice within which human activities develop over time. In other words, students do not take part in an activity for the sake of participation. Such participations have a “historical and social context that gives structure and meaning to what they do” (Wenger, 1998, p. 47). Socially organised activities change over time and thus it becomes the task of the researcher to monitor how collective learning takes place in a community of practice. This perspective allows the researcher to look for any associations between changes that occur in tools and the sociocultural influences in the culture that mediate their transformation.

Based on Vygotsky’s (1978) themes of psychological theory, it can be said that the interdependence between the individual and social processes in the construction of knowledge can be regarded as higher order mental functioning which has origins of development in student and teacher communications, practices and strategies which are mediated by materials, mechanical tools and signs.

It can be interpreted that teachers, students and the various tools available can assist the child develop knowledge which can occur if a joint construction exists among them. Learning creates a zone where the child interacts with the people in the environment through which a variety of internal development processes are awakened. This zone has been referred to as the Zone of Proximal Development (ZPD) (Vygotsky, 1978), where this interdependence of social activity can foster higher order thinking. The concept of the ZPD was originally established as a framework to describe the process of self-development (Chaiklin, 2003; Van der Veer, 2007) as it occurs with the guidance of adults and peers in the learning environment. What Vygotsky found was that children’s social interactions with significant individuals in their lives (parents, peers, teachers, and other adults) profoundly shape their interpretations of the world and higher order thought processes.

The next section will discuss mediated action and elaborate the meaning and importance of tools and how interactions with such tools shape knowledge and surroundings with respect to this study.

2.16.5 Mediated Action

The human experience is shaped by physical and symbolic tools and the interactions with technology which actively shape the character of the human relations with his surroundings. The concept of mediation and mediating tools could be represented as:

$$\text{Human} \Leftrightarrow \text{Mediating tools} \Leftrightarrow \text{World}$$

Verbeek (2000/2005) claims in his book *What Things Do, that*:

> The concept of mediation helps to show that technologies actively shape the character of human-world relations. Human contact with reality is always mediated, and technologies offer one possible form of mediation. On the other hand, it means that any particular mediation can only arise within specific contexts of use and interpretation. (p. 11)

The procedural knowledge which underpins technology is developed through the creation of a process (Williams, 2000), when a solution to a need or response to a brief is desired. There are a range of these processes which are utilized in the development of technology which appropriates the use of tools and artefacts. It is important to clarify the meaning of tools in relation to this study since in a technology classroom students and teachers can resort to various means and artefacts to fulfil both the procedural and conceptual aspects of technology education. The concepts of tool and mediation are key in the socio-cultural theory of learning developed by Vygotsky and his co-workers and students (e.g. Cole, 1996; Kozulin, 1998; Kozulin, Gindis, Ageyev, & Miller, 2003; Vygotsky, 1978; Wertsch, 1991; 1998; 1979; 1985a; 1985b). The central idea is that the structure and development of human psychological processes are co-constituted by the interaction with tools. These tools could be psychological tools, mechanical tools, and language as a tool to communicate. From Vygotsky's point of view, the learners can be seen as individuals-in-society, learning and thinking through these available tools to give meaning to their actions. The use of such tools makes it possible for students to act in an acceptable and functional way in the classroom which enhances and alters both human and product development.

Sociocultural theorists (e.g., John-Steiner & Mahn, 1996; Moll, 1990; Wertsch, 1985a; 1985b) and activity theorists (e.g., Cole, 1996; Engeström, 2001) use the term 'cultural tool' to refer to both physical tools (e.g., pen, computer) and psychological tools such as language. Psychological tools are those symbolic systems specific for a given culture that when internalised by individual learners become cognitive tools. With respect to this study, psychological tools were extensively used within a design culture to help students design and make. (Vygotsky, 1982, p. 166). These psychological tools include various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and technical drawings; all sorts of conventional signs, and so on. (Vygotsky, 1982, p. 137, cited in Cole & Wertsch, 1996). Psychological tools and their complex systems include language, cross-disciplinary concepts, different forms of numeration and calculations, mnemotechnic techniques, symbols, concept diagrams, writing, working schemes, design briefs, prototypes, and all sorts of conventional signs. The centrality of mediation to learning is summarised by Moll (2000):

> To put it simply, human beings interact with their worlds primarily through mediational means; and these mediational means, the use of cultural artifacts, tools and symbols, including language, play crucial roles in the formation of human intellectual capacities. (p. 257)

This research considers the social environment and the individual to be connected and interdependent (Vygotsky, 1978). This study shares the view that the nature of thinking, learning and development cannot be understood without taking account of the intrinsically social and communicative nature of human life. Hence it can be concluded that every mediating system has distinct features that characterize the nature of communication and learning that takes place in that system, which provides a platform to examine integration of science, mathematics and technology in such a system.

This research will explore how communications among various participants was oriented while helping individual members to achieve an effective performance, and the knowledge integrated or generated within the context related interactions. Context-related interactions stimulate the elaboration of conceptual knowledge (van

Boxtel, van der Linden & Kanselaar, 2000) which can then be explored to study the integration of science, mathematics and technology in a technological design context.

2.17 Summary of Chapter

A review of the literature indicates that the term knowledge is not easily or well defined in technology. In the field of epistemology, most debates circle around the short description of knowledge as "justified true belief". This account of knowledge is not suited to defining technological knowledge, since it does not do justice to all types of technological knowledge.

The link between science and technology is such that it is often mistakenly assumed that technology is applied science. Scholars of technology reject this view and insist that technology is a cognitive system consisting of a separate body of technological knowledge. Layton (1971), referring to the "symmetric" relationship between science and technology, notes that technology and science influence each other on a number of levels.

This study does, however, acknowledge that all knowledge is constructed in a social-constructivist and sociocultural context and that the culture of the classroom and practices of the participants play an important role in learning. Constructivist theories of learning have important implications for how this study views knowledge and how it is constructed and learnt in a social context. A technology classroom was analysed from this perspective to investigate the integration of science, mathematics and technology in a technological design context. This put the researcher into a position to understand how the integration of science, mathematics and technology happens during a design activity.

CHAPTER 3 METHODOLOGY

3.1 Introduction

Having defined the aim and objectives of this research, a programme of implementation is now presented with the aim to define the theoretical and methodological underpinnings of the research. The purpose of this section is to justify the research design and methods in terms of the aim and objective of the research.

Included in Chapter 3 are descriptions of the research procedures, data collection procedures, and methods of data analysis used to determine research findings and conclusions. This chapter elaborates the design and methods implemented to investigate the integration of science, mathematics and technology and the issues associated with the implementation of an integrated learning environment in a secondary classroom. Methods of analysis of data are discussed, followed by the criteria for qualitative research that underpin the research programme. The research focuses on the various elements that exist in a technology classroom which lead to the integration of science, mathematics and technology. The research has a component of being interpretive, relying on human interactions (students and teachers) and the interpretations of their experiences, and an element of collaborative research to develop a communicative space in which the researcher and the teacher can participate to innovate educational practices by utilising feedback from the students, at the request of the teacher. There were some instances where characteristics of collaborative action research were evident by working closely in the classroom.

There are certain rules that guide a researcher's actions and beliefs, referred to as a paradigm. To gain a better understanding of why and how the researcher chose the methodological approach in this study, a range of paradigms will be discussed. Following a discussion about the research paradigm, the aim of this chapter will be discussed, then the research design and methodology utilised in this study. In order to describe the variety of research activities undertaken during this study, the data collection activities and associated analysis methods will be systematically presented.

3.2 Research Paradigms

The concept of paradigm was first addressed by Thomas Kuhn in his book *The Structure of Scientific Revolutions* (Avramidis & Smith, 1999; Kuhn, 1970; Maxwell, 2008; Wray, 2011). According to Maxwell (2008), a paradigm "refers to a set of very general philosophical assumptions about the nature of the world (ontology) and how we can understand it (epistemology), assumptions that tend to be shared by researchers working in a specific field or tradition" (p. 224). Weaver and Olson's (2006) definition of paradigm reveals how research could be guided by a certain paradigm by stating, "paradigms are patterns of beliefs and practices that regulate inquiry within a discipline by providing lenses, frames and processes through which investigation is accomplished" (p. 460). These definitions of paradigms are a guide for the researcher that provides a clear perspective of the nature of reality (ontology); the nature of knowledge or how a researcher knows what s/he knows (epistemology); the best way of gaining knowledge about the world (methodology); the values that guide the research (axiology); and appropriate use of language for the research (rhetorical) (Bryman, 2008; Creswell, 2009; Firestone, 1987; Guba & Lincoln, 1994; Sarantakos, 2005). Creswell (2009) suggested these philosophical assumptions are important tenets underpinning the researcher's choice of approach. Paradigms, as a set of philosophical assumptions, are socially constructed and continuously emerging as new complexities of knowledge arise in research. Therefore, to clarify the researcher's structure of inquiry and methodological choices, an exploration of the types of paradigm adopted for this study will be discussed prior to any discussion about the specific methodologies utilized in this study. The next section discusses the types of research paradigms commonly used in educational research.

3.2.1 Types of Research Paradigms

Literature on the classification of research paradigms is inconsistent, as many writers are influenced by their discipline of specialization, such as sociology, psychology and natural science, in classifying types of research paradigms. Various writers like Avramidis and Smith (1999), Dash (2005) and Guba and Lincoln (1994) identify four major research paradigms in social science research: positivism, post-positivism, interpretivism/constructivism, and critical theory. Creswell (2009) and

Patton (2002) suggested four types of worldviews (paradigms): post-positivism, constructivism, advocacy/participatory and pragmatism. As Avramidis and Smith (1999) commented:

> …trying to categorise all educational and psychological research into a few paradigms is a complex, and perhaps impossible, task, … there is little paradigmatic purity and the fact that different labels are used in different texts, the task of identifying paradigms becomes even more perplexing. (p. 27)

However, a critical analysis by Mackenzie and Knipe (2006) shows most of the types of research paradigm used in educational research fall under four main common types: positivism, post-positivism/interpretive, critical theory and pragmatism. These four research paradigms will be discussed in the following sections and the paradigm which best fits this project is then identified and elaborated.

3.2.1.1 Positivist paradigm

The positivist paradigm is based on philosophical ideas developed by the French philosopher and sociologist August Comte in the early nineteenth century (Kim, 2003). Kim notes that "Comte's conceptualization of positivism was based on scientific objectivity and observation through the five senses rather than subjective beliefs" (p. 11). The founders of positivism hold the notion that the only authentic knowledge is that based on sense experience and positive verification. Positivists believe that reality is stable and can be observed and described from an objective viewpoint (Levin, 1988), that is, without interfering with the phenomena being studied. Positivists advocate that reality is uncovered through application of the methods of the natural sciences (Bryman, 2008; Patton, 2002; Sarantakos, 2005). They claim that science provides the clearest ideal knowledge, and researchers should use scientific methods (such as observation, experimentation, hypothesis formation, data collection, forming theory/falsifying theory) as the means of studying the subjective world (Cohen et al., 2007; Bryman, 2008). Predictions can be made on the basis of the previously observed and explained realities and their inter-relationships. "Positivism has a long and rich historical tradition. It is so embedded in our society that knowledge claims not grounded in positivist thought are simply dismissed as ascientific and therefore invalid" (Hirschheim, 1985, p. 33).

The literature (e.g., Cohen, Manion & Morrison, 2007; Dash, 2005; Guba & Lincoln, 1994) identifies the following key assumptions underpinning the positivist paradigm:

- Determinism - the view that events are caused by other circumstances; and hence, understanding such casual links is necessary for predicting and controlling the phenomena under study;
- Empiricism - the view that knowledge is obtained through collecting evidence (via scientific methods) and it provides the basis for laws, theories or hypotheses, which can be verified through observation or direct experience;
- Parsimony - which refers to explaining the phenomena under study in the most economical way possible; and
- Generalisability - which is considered an important value in doing research, with the main focus on generalizing the results from observation of the particular phenomenon to the world at large.

Positivists believe that only quantitative data are considered valid and of high quality (Guba & Lincoln, 1994), and that true knowledge comes from systematic quantification or manipulation of variables (Dash, 2005). The main role of positivist researchers is to test theories and provide data for the development of laws and principles (Cohen, Manion & Morrison, 2011). Positivist education researchers employ a strict research plan designed prior to the commencement of research that allows the replication of the inquiry processes.

Critics argue that positivistic assumptions are inadequate for studying human behaviour (Cohen et al., 2011); in particular, for understanding the subjective states of individuals (Dash, 2005), because human behaviour and actions are complex, and cannot be quantified and studied by the rigorous randomization of variables (Guba & Lincoln, 1994). They suggest that the objectivity of scientific investigation should be replaced by subjectivity (Dash, 2005). As a result of such criticisms, the interpretive paradigm has evolved to respond to the emerging complexity of social science research. The interpretive research paradigm is discussed in the next section.

3.2.1.2 Interpretive paradigm

Interpretivism represents the ideas developed by philosophers from their critique of the positivism paradigm. These ideas challenge the traditional positivist notion of knowledge as the ultimate and absolute truth. Interpretivist researchers believe that social reality is viewed and interpreted by the individual (Bryman, 2008; Creswell, 2009). According to Creswell (2009) "individuals develop subjective meanings of their experiences ... meanings are varied and multiple, leading the researcher to look for the complexity of views rather than narrowing meanings into few categories or ideas" (p. 8). Reality lies in the multiple perspectives of the participants and is inherently subjective. Interpretivism takes an epistemological position that respects individual differences and the social context of the social reality, and assumes that natural science is unable to explain the basis of social human life (Blaikie, 2007; Bryman, 2004; McKerchar, 2008). Following Klein and Myers (1999), the foundation assumption for interpretive research is that knowledge is gained, or at least filtered, through social constructions such as language, consciousness, and shared meanings. In addition to the emphasis on the socially constructed nature of reality, interpretive research acknowledges the intimate relationship between the researcher and what is being explored, and the situational constraints shaping this process (Rowlands, 2005). In terms of methodology, interpretive research does not predefine dependent or independent variables, does not set out to test hypotheses, but aims to produce an understanding of the social context of the phenomenon and the process whereby the phenomenon influences and is influenced by the social context (Walsham, 1995).

This view of reality means that human beings are exclusively unique, active, and autonomous creatures in contrast to the positivist worldview that human beings are passive objects that can be manipulated (Schwandt, 1994). Interpretivists argue that research is a natural participatory process, and meanings of phenomena are created socially through human interactions. An interpretivist researcher is involved in the investigation as a participant observer by immersing him/herself in the life of the research participants in order to observe the live events and participating in social dialogue and social interaction (LeCompte & Schensul, 2010). This way of working helps the researcher to collect reliable and real data as reported by the study participants.

The interpretive research paradigm thus usually uses qualitative research approaches and employs research designs such as case study, biographical research, phenomenology, ideology critique, action research and ethnography (Cohen et al., 2007; Creswell, 2009; Merriam, 2002). Data are collected using techniques such as unstructured interviews, participant observations and documentary analysis (Creswell, 2009; Livesey, 2006; Merriam, 2002). Qualitative research methods and data gathering techniques generally produce richly descriptive data in the form of words and pictures/images that allow the researcher to understand deeply the phenomena under investigation.

3.2.1.3 Critical research paradigm

Critical theory is a tradition developed by the Frankfurt School in Germany, based on the German tradition of the philosophical and political thought of Marx, Kant, Hegel and Weber (Cohen et al., 2011; Weaver & Olson, 2006). Critical theorists are concerned with existing inequalities, oppression, disproportionate distribution of resources and political power within society. The proponents of the critical theory paradigm argue that both interpretivism and positivism inadequately account for social behaviour because they have neglected political and ideological contexts in conducting their educational research (Cohen et al., 2011). They assume that reality or knowledge does not accumulate in an absolute sense, but it is the result of the exchange of logical arguments that erode the historical ignorance of the oppressed society. They believe that engagement in the "dialectical process causes an increased awareness of reality, and from this changes may occur" (Mokhele, 2011, p. 79). According to critical theory proponents the motives of the inquiry should focus on emancipation or transforming of society from oppression, repression, underrepresentation, and disempowerment (Guba & Lincoln, 1994; Peca, 2000; Weaver & Olson, 2006).

Critical researchers assume that social reality is historically constituted and that it is produced and reproduced by people (Myers, 2009). Although people can consciously act to change their social and economic circumstances, critical researchers recognize that their ability to do so is constrained by various forms of social, cultural and political domination. The critical theorist researcher's role is more than describing or understanding the situation; it is to change it or take action by raising the awareness of the powerless people in the society (Cohen et al., 2011; Patton, 2002; Peca, 2000). The intent of critical theory-based research is influenced by political motives to help marginalized people, transform inequalities and create egalitarian democratic society/societies (Creswell, 2009; Hume, 2006; LeCompte & Schensul, 1999).

The aim is to openly critique the status quo, focus on the conflicts and constraints in contemporary society, and seek to bring about cultural, political and social change that would eliminate the causes of alienation and domination. Thus, the paradigm of critical theory encourages evaluators and instructional designers to question and also to evaluate the cultural, political, and gender assumptions underlying the effectiveness of the instructional product or programme (Reeves & Hedberg, 2003). The critical theory seeks to deconstruct the "hidden curriculum" or "text" and search for the "truth" and "understanding within the social context" (Reeves & Hedberg, p. 33). The methodological approaches of critical theory research include action research and ideological critic (Dash, 2005; LeCompte & Schensul, 2010). Researchers using this paradigm believe that the action research approach brings people into reflective logical dialogue that allows them to work as collaborative researchers. In educational research action, research is considered a professional development tool that helps to improve teachers' practice through "cycles of planning, acting, observing and reflecting" (Kember & Gow, 1992, p. 297). Thus, critical theory paradigm research focuses on questioning the status quo and changing the situation rather than just understanding existing situations.

There has been growing dissatisfaction recently among social researchers with "the use of a single qualitative approach to access meaning in data [which] raises questions about what the use of another method would have illuminated in the data" (Frost et al., 2010, p. 2). Thus, they recommended the use of mixed methods or a pluralistic approach that complements the weaknesses of both qualitative and quantitative approaches to studying social phenomena (Creswell, 2009; Morgan, 2007). They believe that the use of a pluralistic approach where inquiry is conducted using more than one paradigm provides richer information that helps the researcher to explain more deeply the phenomenon under study. Therefore, critics have developed the pragmatism paradigm as a pluralistic or mixed approach for studying complex problems in research, and this pragmatism paradigm is discussed in detail in the next section.

3.2.1.4 Pragmatism research paradigm

Pragmatism is a new philosophical approach to inquiry that rejects the application of positivism, critical theory, and post-positivism/interpretivism in studying reality. The followers of this paradigm reject the notion of selecting a research paradigm and recommend the use of a pluralistic approach to studying research problems (Johnson & Onwuegbuzie, 2004; Lodico, Spaulding, & Voegtle, 2006). They argue that what is important for a researcher is not the choice of the research method but what works best in order to address the research problem under investigation and provide answers (Creswell, 2009; Patton, 2002). They advocate mixing qualitative and quantitative research methods to study social phenomena (Creswell, 2009; Johnson & Onwuegbuzie, 2004; Morgan, 2007).

Pragmatic researchers usually look for the middle ground between the philosophical dogmatism and scepticism in investigating social problems (Johnson & Onwuegbuzie, 2004; Morgan, 2007), and they consider truth to be what worked in that particular time and context (Creswell, 2009). For example, Morgan (2007) argued that pragmatist studies depend on ‘abductive reasoning’- where the researcher uses both induction and deduction reasoning approaches; intersubjective reasoning - where the researcher works back and forth between the subjective and objective frameworks; and transferability of the findings to other contexts. These forms of reasoning are considered the main values underpinning pragmatic studies. Other researchers have argued that pragmatism directly links theory with praxis (Levin & Greenwood, 2011). Petrou (2007) concluded that “pragmatists are not committed to any philosophy and they cannot see the importance of discussing assumptions about truth and reality when designing their research. What is important to them is what works in practice” (p. 1740). Thus for a pragmatist researcher, what is important is what works to answer the research questions. The next section discusses the paradigm selected for this study.

3.3 Interpretive Paradigm and Critical Theory as Paradigms of for this Study

According to Maxwell (2008), the selection of a study paradigm "is not a matter of free choice" (p. 224), but depends on the researcher's prior assumptions about the world, topic of the study, and how the study can be easily understood by end users. Selecting an appropriate research paradigm involves the process of assessing which paradigm best fits "your own research assumptions and methodological preferences" (Maxwell, 2008, p. 224).

To achieve the purpose of this study, the interpretive paradigm was adopted because its tenets allow the researcher to conduct a thorough investigation of the social phenomenon as reported by the study participants and how they interpret their social cultural setting (Cohen et al., 2011; LeCompte & Schensul, 1999; Russett, 2008). It also allows the researcher to immerse him/herself in the subjective perceptions or lived experiences of the participant, which helps the researcher understand the culture, interactions, group norms and the reasons for their actions (Cohen et al., 2007; Denzin & Lincoln, 1994; Scott & Usher, 1999). In this study the researcher assumed that participants' reality is mediated by humans' interaction with their external world, such as the historical background and the cultural context in which they live (Golafshani, 2003; Grbich, 2007; McKerchar, 2008; Opie, 2004; Sarantakos, 2005; Stake, 2010).

Since the purpose of the study was to investigate the integration of science, mathematics and technology in a technology classroom, the researcher believes that using the interpretive paradigm as a lens for the investigation would enrich the research process, because meanings in interpretive research are negotiated during the immersion of the researcher in the participants' worldview (Becker & Bryman, 2004; Cohen et al., 2007; McKerchar, 2008; Sarantakos, 2005). Studying technology teachers' and students' actions, practices and views using the interpretive research paradigm would be likely to generate insightful data for understanding their perspectives on the world and the reasons for their practices and perceptions.

This thesis adopted the interpretive paradigm because it allows the study of a small sample of participants located within particular social and cultural contexts (Grbich, 2007). Even the emergent design characteristics of the interpretive paradigm (Jacobson, Gewurtz, & Haydon, 2007) will assist the researcher to be flexible in studying reality in an unknown context, where he/she does not have an in-depth awareness of what he/she going to investigate in advance. Interpretive inquiries are not generalisable (Grbich, 2007); however, they can generate rich data, which allows the findings to be useful in other settings with similar populations and similar social and cultural contexts (Russett, 2008; Teddlie & Yu, 2007). Hence, the researcher in this study believes that these findings may highlight the practices of the teachers and students in a technology classroom which leads to the integration of knowledge from science, mathematics and technology.

The collaborative nature of interpretive research processes (LeCompte & Schensul, 1999), including characteristics such as reciprocal relationships between the researcher and participants, and of negotiating meanings with participants, "give interpretive inquiry its own power dynamics and thus its own ethical conundrums" (Jacobson et al., 2007, p. 2). These conundrums mean that ethics in interpretive research is a significant subset of the inquiry process, because, in order for the researcher to immerse him/herself in the participants' world and give their perspectives a voice, the researcher and participants must mutually agree to the processes of investigation. The mechanism of moderation of ethical issues in an interpretive paradigm is natural during the research process.

This chapter also reports on the research design adopted and some instances where collaborative action-research was implemented and the process the various stakeholders experienced. Goldstein (2000) notes that "collaborations in which university-based researchers enter into participatory relationships with classroom teachers have become increasingly prevalent in educational action research" (p. 517). Much educational research literature shows that collaborative action research partnerships can be very effective but they come with their own challenges and conflicts (Johnsen & Normann, 2004; McLaughlin, 2006; Orland-Barak, Kemp, Ben-Or, & Levi, 2004). The researcher and teacher contributed their expertise to form a collaborative and productive environment for teaching and learning as suggested by Kemmis (2007).

The participants in this study were given opportunities to develop trust among themselves and with the teacher and researcher. The literature draws attention to how complex the formation of a communicative space can be (Habermas, 1987; Habermas, 1996; Kemmis, 2001; Kemmis & McTaggart, 2005); however, in this study measures were taken, such as being friendly with the participants, assuring confidentiality and respecting individual opinions and rights, to make the participants confident enough to exchange their perceptions and views so they could work with mutual understanding and consensus.

There are numerous ways for teachers to become involved in designing classroom materials and resources under the guidance of a researcher (design-based research). Action research has been identified as a way to help teachers, practitioners and educators to actively design, revise and alter their materials and resources. The primary concern in conducting action research is to change. This concern is grounded in the idea that development and innovation are an essential part of professional practice (Altrichter et al., 1993). There were instances in the classroom where extensive exploration of a particular situation took place and potential was identified to integrate science, mathematics and technology. The teacher formulated a plan to integrate conceptual knowledge from science which might help students understand the scientific reasons behind observed phenomena. After the use of the resources/materials specifically designed to integrate knowledge was infused in the classroom, effective data collection methods were incorporated to collect feedback from both the teachers and the students reflecting their perceptions on such an intervention. The researcher shifted his role to a facilitator at times to provide guidance and advice based on classroom observation and student feedback. Action research is considered as a fruitful way to design and revise classroom lesson materials but it requires the teacher to become a researcher and the researcher to become a teacher.

Ponte (2002) notes that learning to perform action research is a difficult and intensive process which requires proper guiding facilitation that will determine the gains for the teacher. The teacher and the researcher maintained a quality professional relationship in the classroom which led to sharing of ideas, thoughts and concerns which emerged during the course of the product development. The teacher developed materials and resources with an aim to change and improve the classroom environment to be more interactive and integrative for better student learning and understanding. Data were collected for the four school terms of the year 2013 where 19 students and a full time technology teacher worked actively in developing a product.

This study will adopt an interpretive and the critical theory paradigm since the study is based on the perceptions of the participants with a view to changing the future teaching practices.

The next section provides a brief background to the study followed by the design of the research.

3.4 Background

By looking at a secondary technology education classroom in New Zealand, this thesis aims to investigate the integration of knowledge from science and mathematics in a technological design context to implement an integrative STEM environment. This study aims to investigate and elaborate the intended and unintended integration that takes place in a technology classroom during a collaborative action research process where the teacher experimented with integration of knowledge to explore the feasibility and possibilities of this approach to his teaching. One technology teacher participated in this research to expand his knowledge and skills so they could effectively implement an integrative learning environment in a future technology classroom. Using observations and structured questions, the researcher examined high-school student's practices and perceptions of teacher adaptations to establish an integrative learning environment in future technology education classrooms. Students included in this study represented low achievers, average achievers, high achievers, and a couple of students with learning disabilities.

3.5 Design

This research required an in-depth analysis of the perspectives of the key participants (teachers, students) with data collected individually from the teacher and from the group of students. The data collected were organized by recording and digitally storing it to allow refinement and further interpretation of findings. Therefore, this study largely employs a case study research methodology using interpretive and critical theory techniques involving collection of both qualitative and quantitative data. This research aims to study the practices and perceptions of a teacher and students in a technology classroom to understand integration suggested that the following characteristics had to be considered in deciding on the data collection methods:

a) Whether the phenomenon under investigation presented a situated, natural and bounded entity;
b) How integration happens in a technology classroom, taking into account the perceptions of the students and their teachers;
c) Which factors fostered or hindered any integration in a classroom; and
d) An intensive investigation of the practices of the teacher and students which led to the integration of science, mathematics and technology in a technology classroom.

These characteristics indicated that a case study approach would be appropriate to answer the research question. Case study is "an intensive description and analysis of a phenomena or social unit such as an individual, group, institution or community" (Merriam, 2002). The aim of a case study according to Hitchcock and Hughes (1995) is to "locate the 'story' of a certain aspect of social behaviour in a particular location and the factors influencing this situation" (p. 74). Yin (2009) suggests that case study design should be considered when:

a) Investigating a contemporary event where the researcher cannot manipulate behaviour of the participants;
b) The focus of the study is to answer 'how' and 'why' research questions;
c) The researcher has little or no control over the contextual factors that are relevant to the study; and
d) There are no clear boundaries between the phenomenon and context.

A case study design is best for investigating in the natural setting (in this case a technology classroom), where the researcher does not manipulate the behaviour of the participants (students and teachers) which aligns well with the interpretive paradigm. Also, this design allowed the researcher to make observations and provide detailed descriptions of the research problem; this approach helped in understanding the classroom events, practices (students and teachers) and interventions adopted by the teacher to integrate science, mathematics and technology. A case study design also allows the researcher to investigate the complex integration in a classroom in a holistic manner, using multiple sources of evidence. Mason and Bramble (1997) also consider that case studies "are conducted to foster understanding of how current situations or characteristics developed for practical reasons" (p. 39). The major aim of the research was to investigate how the integration of science, mathematics and technology takes place in a technology classroom, or in other words, looking into the "factors that contributed to the characteristics of the case" (Mason & Bramble, 1997, p. 39) and supporting an integrative learning environment (critical theory paradigm).

A case study approach was, therefore, the best methodology for addressing the aim and objectives of this research. The qualitative research method of case study proved to be an appropriate research design for exploring aspects of integration in a technology classroom. Through the use of case study methodology, complex casual links during real-life instructional conditions that offered opportunities for effective integration were studied, real-life contexts in which the instructional conditions that offered opportunities for effective integration were described, specific instructional conditions that offered opportunities for teachers to enhance student learning were documented, and situations in which instructional conditions that offered opportunities for effective integration were also explored.

As technology is an area of the curriculum that is not as widely researched as others, especially how integration happens in its natural settings, this research provided an opportunity to examine a unit (a class of students and their teachers) in considerable detail, such that it may provide insight into the workings in other such units.

The teacher and students experienced their usual learning environments in accord with normal practice. The program was developed by the teacher to suit the needs of his class, as he perceived it was based on the interests of the students and adhered to the syllabus documents. The researcher in this study should be considered as taking on a primary role of an observer, and at times as a secondary role of a collaborative colleague. Crucial points for integration were detected beforehand (except instances where it might happen naturally) and steps were taken to ensure that accurate and precise cross-disciplinary knowledge was provided to the students which would make learning more meaningful.

3.5.1 Assumptions and Rationale for a Qualitative Design

The use of a qualitative research design, specifically case study, resulted in gathering rich and descriptive details regarding the integration of science, mathematics and technology in a technology classroom. This type of design enabled the researcher to distinguish between explanation and understanding as a purpose of design, to distinguish between a personal and impersonal role for the researcher and to maximize what was learned (Stake, 1995). The empathetic nature of case study methodology allowed the researcher to develop a thorough description of the classroom experiences, findings, and conclusions about strategies, practices, and perceptions of students and teachers towards the integration of science, mathematics and technology in a technology classroom.

3.5.2 Participants

A case for this research was developed by examining a single classroom (Year 11) and their technology teacher in a regional Waikato school. Initially, the class and teacher were recruited through informal enquires directed to both the teacher and the principal of the school identified. A single class from this school was suggested by the teacher and then recruited to participate in this study.

The teacher was comfortable with the intentions of the research and was prepared to work extra hours if required. He was keen to explore how the integration of cross-disciplinary knowledge took place in his technology classroom, which led to his recruitment in this study. Other factors were also considered based on the location and accessibility for the researcher, size of the classroom and the type of the school. Permission was then obtained from the Faculty of Education research ethics committee, the school principal, teacher, students and their parents/guardians.

3.5.3 Researcher's Role

In a qualitative study, the researcher must have three skills: tolerance for ambiguity, sensitivity, and communication skills (Merriam, 1999). In addition to being able to tolerate ambiguity and behave as a sensitive observer, being a good communicator and a good listener was a necessity. Merriam also stated that a good qualitative researcher looks and listens everywhere.

My education and my professional development and experiences contributed to my choice of qualitative research. During my tenure as a teacher, I acquired knowledge and supervisory skills as a STEM associate, participating in the STEM delivery and Evaluation Programmes in the suburban schools in Manchester and Leeds, England. As a STEM associate, I observed and helped deliver sessions across school districts, developed observation notes, and wrote short reports based on the student performances and teacher experiences. These reports were reviewed by the programme managers, revised, and then handed back to the school principals.

Subsequently, as a high school STEM associate responsible for the delivery and evaluation of the STEM programmes, I became aware of the need to enhance my knowledge and expertise in the area of STEM integration, especially through a programme which could naturally integrate cross-disciplinary knowledge while students work on designing and making a product. Consequently, I began a doctoral programme in technology education, a subject area which has potential to integrate knowledge from other disciplines in the classroom while students design and make.

My work experience provided me with the skills and opportunity to undertake a qualitative study. The methods of data collection, interviews, field observations, and document analysis were areas in which I had had previous professional experience. My ability to tolerate ambiguity, to be sensitive to the needs of students and staff, and to communicate effectively was further enhanced and honed by frequent advice and guidance provided by my supervisors. The tasks of gaining access and entry into the research site, interviewing teachers and students, recording observations in the classroom, and engaging in collaborative conversations related to data results were research skills with which I was at ease.

The researcher role was clearly understood by all participants and he was clearly present in the classroom during all the sessions for data gathering. The students' ability and willingness to tell their perceptions and stories and shared their ideas regarding the project with their peers, their teachers and most importantly with the researcher improved with time. The students became familiar with the researcher and understood that the researcher was going to be a regular presence in the classroom. In the letter to parents and students the researcher's role was clearly established. The researcher also articulated his role to the students the first time he observed in the classroom so during the first two weeks, the participants were more aware of his role and become comfortable with the presence of the researcher in the classroom.

To avoid a degree of artificiality the researcher established a rapport with the students during Terms 1, 2,3 and 4 and began all conversations with non-threatening questions. The researcher also spent most of the time with the students in the classroom and workshops to establish a rapport, based on respect rather than power. The students referred to the researcher by his first name and clearly differentiated him from the technology teacher.

3.6 Assurance of Confidentiality

Because this study included human subjects, including children aged 15-16, the assurance of confidentiality for participants was mandatory. Therefore, consent forms reviewed by both the university's ethics committee and the research team had to be signed by teachers and students and their parents/legal guardians. The signed consent forms provided contractual agreements for confidentiality among participants. The class observations and interviews were audio-taped. Although individual teachers, students and members of student focus groups were audio-taped, teacher and student anonymity were maintained. There was no videotaping. The researcher personally scripted and transcribed field observation notes, and taped interviews of classroom observations each day.

Throughout the thesis, the case site is referred to as the school; teacher by 'T' in the conversational scripts; student focus groups as Focus Groups One, Two, or Three; and student class members by assigned pseudonyms like S 1, S 2 or S 3 during classroom discussions where it was not practical to identify the particular student.

The students were also assigned pseudonyms like AB, BC or CD when the researcher became familiar with the students and could identify who said what.

3.7 Data Sources

The data collection process was intended to allow the development of a "picture" as discussed by Jones (1997) of student capability in simultaneity with the practices and perceptions of the teacher and students, and the teaching plans/strategies they employed for any intended/unintended integration to happen in this technology class. It was designed to allow insights into technological processes as they appeared from the range of participants' perspectives (Burns, 1994). Furthermore, to investigate how integration of science, mathematics and technology happens in a technology classroom, it was important to examine the practices and the issues associated with the implementation of such an integrative learning environment. This included classroom strategies utilised by the teacher, the design process implemented by the teacher, intended/unintended integration of cross-disciplinary knowledge and the manner in which the participants characterised technology as they perceived it in the classroom.

The methods of data collection yielded information needed to examine interactions in the classroom environments and to gauge individual perceptions of integration. Patton (1990) reasoned that:

> Multiple sources of information are sought and used because no single source of information can be trusted to provide a comprehensive perspective.... By using a combination of observations, interviewing and document analysis, the fieldworker is able to use different data sources to validate cross-check findings. (p. 244)

Patton characterized on-site investigation cases as observing what is going on, talking to people and examining documents. These methods of data collection proved to be beneficial for this case study. The qualitative data would be used to investigate the categories of knowledge (science, mathematics and technology) used by the students in a technology classroom. The data for qualitative analysis was collected using classroom observations, interviews (teacher and students), discussions (teacher and students) and questionnaires during Terms 1 and 3, and the technology portfolios of the students.

Each interview session began with a review of the purpose of the study, the procedures for the interview and the assurances of confidentiality as outlined in the consent forms. The teacher chosen for the study determined the interview times. The teacher was interviewed during their planning periods and students were also casually interviewed during the regularly scheduled technology classes. Any follow-up contacts with teacher or students regarding collecting more data or reconfirming the meaning of the data were made either during the teacher's planning periods or at times collaboratively agreed upon with the teacher.

All interview participants were interviewed in their classroom environments. For the most part, interviewing in a qualitative investigation is more open-ended and less structured (Merriam, 1998). Merriam cited tape-recording the interview as the most common way to record and review interview data. This practice ensures that everything said is preserved for a detailed analysis at a later stage. Structured, open-ended interview questions were determined in advance and designed with the research questions in mind. Focus group interviews with the students lasted between 30-40 minutes on average. All interview data collected was transcribed on the same day and stored securely in a digital format.

The initial meeting with the technology teacher created an environment for an honest appraisal of the entitlement of the research and development of rapport among the teacher, students and the researcher, to facilitate a reciprocal approach which was maintained throughout the study. This allowed discussions to be facilitated in which the researcher and the teacher could openly share their problems and perceptions in the classroom as the research progressed. The next section will discuss in detail the various methods employed to collect data from the classroom.

3.7.1 Observations

Observation is defined as “systematic watching of behaviour and talk in naturally occurring settings” (Pope & Mays, 1995, p. 43). Observational data is useful when the study objectives are to understand the phenomena in a cultural setting hidden from and not known by the public (Curry et al., 2009; Lambert & McKevitt, 2002).

This method provides reality checks of what people say, as people often do different things to what they say or they intend (Kawulich, 2005; Robson, 2002). Observation allows direct noting and recording to check any difference between expected performance and actual performance on a single task or a series of tasks (Clardy, 1997; Phillips, 1991). Robson (2002) notes that a participant observation structured observation data collection method is used mainly by qualitative researchers. The participant observation method is defined as a “data collection technique that requires the researcher to be present at, involved in, and recording the routine daily activities with people in the field setting” (Schensul, Schensul, & LeCompte, 1999, p. 91).

This study employed the participant observation technique to examine and afford a first-hand view of teacher and student practices and interactions both in the classroom and the workshop. As an outsider, an observer will notice things that have become routine to the participants themselves, and things that may lead to understanding the context. Observations are also conducted to triangulate prominent findings (Merriam, 1998). Classroom observations provide a view of what actually happens in the natural field setting.

The classroom observation was conducted four times a week over a period of 10 months (Feb 2013-Dec 2013) at a school in Hamilton (Year 11). The researcher attended classroom lessons prior to the beginning of the study to familiarise himself with the classroom workings and participants. The researcher observed the practices of students/teacher which led to any integration of science, mathematics and technology in the technology classroom. Classroom observations enabled the researcher to learn about the perceptions of the students about integration. Teacher interventions or any diffusion of cross-disciplinary knowledge was identified by the researcher and appropriately audio recorded when the information was provided to the class. The researcher wanted to identify any former/prior knowledge students bring to the classroom to design and problem solve. An observation guide (field note) was developed to help ensure all relevant instances were noted during the class periods and to also to capture any unanticipated scenarios. After each observation was conducted, data were carefully stored and transcribed for initial analysis.

3.7.2 Questionnaires

Self-completion questionnaire surveys are very widely used as a data collection method in health service, education and social science research (Bowling, l997; Lister-Sharp et al., l999; Scott & Usher, l999). They are considered to be a cost effective method of collecting data from a large number of people in a relatively standardized way. In some situations, self-completion questionnaires may allow people to express views on issues about which they may not feel comfortable talking with an interviewer (Boulton, l994; Oakley et al., l990).

Most of the research methods literature relating to the use of questionnaires focuses on issues about reliability and validity. The primary concern is with ways of designing questionnaires so as to maximize the accuracy of, and reduce bias in, the data collected. Attention to the length, layout, readability, language used, order of questions and content of questionnaires is advocated in order to improve the quality of the data obtained (Bryman, 2001; Cohen & Manion, 1998; Johnson et al., 1994; Robson, 1993).

Good questionnaire design is crucial (Bulmer, 2004; Creswell, 2003). The principal requirement of questionnaire format is that questions are sequenced in a logical order, allowing a smooth transition from one topic to the next (Sarantakos, 2005). Advantages for open-ended questioning include freedom and spontaneity of answers, opportunity to probe and use-fulness for testing hypotheses about ideas or awareness (Op-penheim, 1992). Open questions allow the respondents time and space for free-opinions which invite participants to share their understandings, experiences, and interpretations of social processes and situations (McGuirk and O'Neill, 2005). Since a large variety of answers could be provided for any one question, analysis of the results could be challenging, as I experienced from my own research.

This study found it appropriate to introduce open-ended questionnaires at critical stages to collect data informed by the classroom observation and previous questionnaires and the practices of the teacher and students. The intention was to capture the thoughts and ideas of the students in a written format as they were designing and making their products. It was not feasible to conduct student interviews during the school terms due to the timetabling and time constraints.

An initial questionnaire (T1) which included open-ended questions was distributed at the beginning of the study (1st – 2nd week) during the initial stage of the project. Follow up questionnaires (T2 and T3) were administered towards the end of Terms 1 and 2 respectively, which were developed over time and informed by the answers of the preceding questionnaires, the researcher's classroom observations and teacher feedback.

The initial questionnaire (T1) was developed to identify why students chose technology as a school subject and to capture their experiences in doing technology. Questions were designed to capture their perceptions while working in a natural classroom setting and not leading them to identify the categories of knowledge (science, mathematics and technology) at the initial stages of the research. The researcher was trying to gain a better understanding about students perceptions of what they are going to do in the classroom, their experience with designing (if any), design ideas, and specific knowledge/information students may need to proceed with design and problem solving. The questionnaires T2 and T3 were developed at later stages to capture the big picture of how students integrated knowledge intentionally/unintentionally to solve a problem in a technology classroom. The researcher wanted to investigate whether students realise that they are integrating knowledge from different domains or they just do it naturally because they need to design, make and problem solve.

A final questionnaire (T3) at the end of Term 3 was introduced which required all students to indicate the extent of their understanding informing the making and functioning of their project component without any direct reference to knowledge from science, mathematics and technology. Again, the appropriate questions for the questionnaire were informed by classroom observations and the feedback from the teacher.

3.7.3 Interviews (Teacher)

Interviews offered a view of teacher's insights and perceptions into the case environments. "We normally interview people to find out from them those things we cannot directly observe.... We cannot observe feelings, thoughts, and intentions.... The purpose of interviewing, then, is to allow us to enter into the other person's perspective" (Patton, 1990, p. 196). Interviews are a "very good way of assessing people's perceptions, meanings, definition of situations and constructions of realty" (Punch, 2005, p. 168). Robson (2002) classified interviews into three main types: fully structured interviews, focused/semi-structured interviews, and unstructured interviews. This study adopted a semi-structured interview approach to obtain data from the participants.

Kvale and Brinkmann (2008) defined a semi-structured interview "as an interview with the purpose of obtaining descriptions of the life world of the interviewee in order to interpret the meaning of the described phenomena" (p. 3). Semi structured teacher interviews (of approximately 40 mins), were conducted at the end of Term 1, 2 and 4 to capture and discuss in detail the introduction of any cross-disciplinary knowledge and to reflect their practices and experiences in the classroom regarding integration. The interview with the teacher was conducted to develop detailed insight into the process of integration and to record his perception about integration, rationales for the methods used in the classroom and aspects which can result in better integration in the future. The teacher interview questions for Term 1, 2 and 3 have been included in Appendix B. The teacher interview questions were gradually developed during Term 2 and 3, informed by the previous interview and the classroom observations.

3.7.4 Discussions (Teacher and Students)

Discussions with the teacher/students formed a basis for clarifying the purpose, procedures, and significance of the study. Discussions provided clarifications of data assessments and enabled collaboration with teacher to highlight the rationale for specific practices of the students and teacher. One of two methods of data collection predominates; the other plays a supporting role in gaining an in-depth understanding of the case (Merriam, 1999). Although interviews, field observations, and documents provided data needed for triangulated comparisons, formal/informal discussions with teacher/students provided in-depth understanding and perceptions about the context of the study on a daily basis. For this study, it was the frequent discussions with the teacher and students which proved to be more dominant in terms of value than the other methods.

3.7.5 Focus Group Interviews

Focus group interview is a qualitative research method used to collect in-depth attitudes, perceptions and experiences from a specific group of people on a defined topic (Cohen et al., 2007; Robson, 2002; Stewart, Rook, & Shamdasani, 2007). Focus group discussion is defined as a "method of group interview which explicitly includes and uses group interaction to generate data" (Pope & Mays, 1995, p. 43) and is guided by the researcher. This method helps the researcher to gain hidden insights that are difficult to unveil through straightforward interviews or discussion (Hydén & Bülow, 2003). Focus group interviews have natural control mechanisms of data collection because the participants themselves tend to provide views to balance extreme opinions during the discussion (Bernard, 2000; Punch, 2005; Robson, 2002). Kitzinger (1995) reported that during focus group discussions, participants have the opportunity to speak, ask questions of other participants and respond to the comments of others, including the researcher, so it has a natural checks and balance mechanism that lends authenticity to the data collected.

Student focus-group interviews were used to include the student voice in the study regarding their experience and perceptions of integration. Because being interviewed one-on-one by an unfamiliar person may have made students hesitant to provide information, focus group interviews with fellow students proved to be advantageous. Students openly shared opinions and perceptions related to their work in the classroom and workshop. Care was taken to encourage all participants to talk and to monitor individuals who may have dominated the conversation (Creswell, 1998).

Group interviews helped answer the main research question by collecting data related to the categorisation of knowledge from science, mathematics and technology and its application and utilisation in the context of technology. Group interviews with the students were conducted towards the end of the school term to identify the various categories of knowledge incorporated in their design, their thoughts about and perception of the categories of knowledge from science, mathematics and technology. This data would also help to identify any knowledge newly constructed by the students from past experience/knowledge to solve problems while designing. The focus group interview questions were refined on the basis of the classroom observation, input from teacher discussions and questionnaire data in Terms 1, 2 and 3 respectively. The focus group interview questions conducted in Term 4 have been included in Appendix A.

3.7.6 Document Analysis

Documents provide rich information that cannot be accessed through interviews, focus group discussions or observation (Patton, 2002). With the consent of all participants, the researcher reviewed and analysed student's technology portfolios, pictures of the designed components and final products. Student records provided an insight to the categorisation and utilisation of knowledge that led to any integration which would further triangulate with the other data.

The next section will highlight the analysis process employed during and after the phases of data collection.

3.8 Analysis

The analysis of the data for this research took place within a social constructivist and socio-cultural framework that sought to explain the integration of science, mathematics and technology in a technology classroom. As suggested by Guba and Lincoln (1981, 1989), a number of assumptions were made. The first of these assumptions is that there are multiple sources of realities, none of which could be considered more true than another, and none are considered in isolation. There have been many instances where the researcher necessarily interacted and may have affected the phenomenon under study in an attempt to understand the influence of the intervention on the information, which relates to this second assumption (Guba & Lincoln, 1981). The third assumption is that the knowledge the researcher is attempting to understand is focussed on particular events and it is the differences that are observed between such events that often reveal more than the similarities (Guba & Lincoln, 1981). These assumptions place this research in a phenomenological interpretation (to explore in details how participants make sense of their world) of the perceptions, experiences and social interactions of the students and teacher and is aimed to frame, expose and study to some degree the shared and individual understanding of these participants in terms of integration of cross-disciplinary knowledge.

For this study, the researcher adopted a thematic analysis approach as an investigation on integration would be carried out by the analysis of data collected in the classroom, questionnaires, individual interviews (teacher), discussions (students and teacher), focus group interviews (students) and document analysis to detect patterns and regularities, to formulate some tentative hypotheses that the researcher could explore, and finally to develop some conclusions for integration. This analysis technique can provide a wide variety of information in a systematic manner in understanding and interpreting observations for answering the research questions.

The researcher was able to bring his experiences from practice and the literature to carry out the research and its analysis, and he was aware of the need to shield against allowing this experience to influence conclusions and interpretations. This has been referred to as subjective bias by Burns (1994) which needed to be considered in the data collection and analysis by the researcher, although it should be clear that this research aims to capture the nature of a technology classroom and how the integration of science and mathematics takes place in technology. The goal of this research can also be said to "explicate how objects and experiences are meaningfully constituted and communicated in the world of everyday life" (Holstein & Gubrium, 1994, p. 264).

3.8.1 Analysis during Data Collection

The data collected were analysed in parallel with their collection with the main aim of understanding the initial interpretations of the raw data and to inform the next step of data collection. A coding scheme to process the data was then developed to help understand integration in a classroom and to facilitate later interpretations. This coding scheme was influenced by the initial interpretations of the data that evolved into a story which will be presented in subsequent chapters. The researcher recorded and stored all available data, revisited the retrieved data to make initial rich interpretations which proved to be a useful starting point, as indicated by Huberman and Miles (1998).

Firstly, the collection and processing of data was made through observation field notes, audio recordings taken during classroom observations, interviews, discussions, photographs of students working on their products and student technology portfolios. A daily account of every classroom period was maintained throughout the year by the researcher as a summary of field notes and self-reflective remarks during and after data collection. Frequent reflections were developed on the collected data at the end of every term to ensure that the initial interpretations were refined, modified or discarded as the study progressed. The raw data were progressively written up and a first level thematic analysis was performed. The initial reflections were generated in addition to the field notes which represent a guide to the development of initial ideas. A general documentation of collected data (from observations, field notes, audio recordings, discussions and interviews) and analysis of the work done was also retained in the form of a blog which allowed for checking and cross-referencing between the data sources. All of the above data presented a platform for the development of an analytical file/reflective blog and provided an audit trail of the data collected.

The reflective blog was generated from the available raw data through a cyclical process that refined and rejected assertions throughout the data collection process. This provided guidance to the subsequent data collection process as well as being a tool for reflection. This blog allowed the researcher to access data mainly from the classroom observations to chronological episodes or thematically collated material. The periodic revision of this data allowed a build-up of the understanding of the process of integration in a technology classroom environment and the practices of students and the teachers to test researcher-generated assertions which could be explained through reference to this blog. The interpretation and analysis of the data progressed throughout the research to keep the researcher informed about the findings and their progression in order to develop the next plan of action in terms of the collection of data. The outcome of this process resulted in developing a story that is presented in Chapters 4, 5 and 6.

3.8.2 After Data Collection

After all data were collected, transcribed, and documents scanned and photocopied, the next step was to identify the units of meaning in the data (Maykut & Morehouse, 1994). The search for meaning was accomplished by first identifying the smaller units of meaning in the data, which later served as the basis for defining larger categories of meaning. The process undertaken could thus be described as a hermeneutic dialectic process (Guba & Lincoln, 1989), the idea being to make complete references to the dialectic between the understanding of the text as a whole and the interpretation of its parts, in which descriptions are guided by anticipated explanations (Gadamer, 1976). The understanding of the interpreted meaning would be constantly from the whole to the part and back to the whole as indicated by Gadamer. Ricoeur (1974) notes that "Interpretation is the work of thought which consists in deciphering the hidden meaning in the apparent meaning, in unfolding the levels of meaning implied in the literal meaning" (p. xiv). Each unit of meaning identified in the data stands by itself in order to be useful for analysis.

NVivo was used as a software tool that complemented the researcher's work on qualitative analysis and mixed method research. The installation of classroom observational field data, pictures, interview scripts and technology portfolios was carried out by uploading the digital data in the software and coding the data to form queries; further analyses of the coding and data were carried out to form themes.

The research aims to explain the social reality of integration in terms of the participants' shared beliefs and practices in technology by the utilisation of cross-disciplinary knowledge. All the observation field notes, interviews and document records of the perceptions of the actors (students and teacher), describes certain events (see Ricoeur, 1981) to 'make sense' of the collected data. The researcher's understanding of the whole social setting was continually revised and re-analysed in view of the reinterpretation of the parts. A detailed account of the steps taken to analyse the collected data will be presented and discussed in the following sections.

3.9 Approach

The research investigates the practices and perceptions of the teacher and his students regarding how integration of science, mathematics and technology happens while involved in a technological activity. Radnitzky (1970) cites Gadamer as saying that "We don't have to imagine oneself in the place of some other person; rather, we have to understand what these thoughts or the sentences expressing them are about" (Radnitzky, 1970, p. 27). According to this view of Gadamer, the researcher needs to be aware of his historicity with no deliberate attempt to lie, deceive or mislead participants to understand the integration under investigation.

3.9.1 Hermeneutic Dialectic Approach

The hermeneutic dialectic approach as outlined by Gadamer (1975) overcomes most of the weakness of the pure interpretive approach as summarized by Orlikowski and Baroudi (1991, p. 18):

- The interpretive perspective does not examine the conditions, often external, which give rise to certain meanings and experiences;
- Second, research in this perspective omits to explain the unintended consequences of certain actions, which by definition cannot be explained by reference to the intentions of the humans concerned;
- Third, the interpretive perspective does not address structural conflicts within society and organizations, and ignores contradictions which may be endemic to social systems; and
- Finally, the interpretive perspective neglects to explain any historical change; that is, how a particular social order came to be what it is, and how it is likely to vary over time.

One of the key differences between a purely interpretive approach and dialectical hermeneutics is that the researcher does not merely accept the self-understanding of participants, but it seeks to critically evaluate the totality of understanding in a given situation. The researcher accounts for the participants' own perceptions and thoughts historically and in terms of changing environment while involved in a technological activity. The hermeneutic dialectic perspective in an integrative learning environment will try to emphasize both the subjective meanings for individual actors and the practices embedded in that social structure (classroom and workshop) which enable such meanings to take place.

Taking into account the differences between critical theory and the hermeneutic dialectic approach, this research intends not to assume from the outset what the most important conflicts and contradictions are in contemporary organizations (see Poster, 1989; 1990). Rather, the researcher went simultaneously with the critical analysis of the classroom and its practices maintaining a dynamic interplay between a hermeneutic analysis and theoretical critique, in which the critique is firmly grounded in the reality of the classroom. This was accomplished by conducting more informal spot interviews (students and teacher) and collecting as much data as possible to provide a better understanding of integration in a technology classroom.

The hermeneutic dialectic approach accepts critical views and opinions of the participants on a particular topic to evaluate and transform social reality. However, dialectical hermeneutics requires that researchers develop a critical awareness and understanding of, in this case, the relationship between technology and integration of cross-disciplinary knowledge. Since the research aims to highlight the complex nature of integration in a technology classroom, the hermeneutic dialectic approach will help to achieve the real picture of the complexity of such integration in the classroom as a social system. A hermeneutic dialectic analysis of technological activity requires analysing a technology classroom from different perspectives.

3.9.2 Key Incident Analysis

A more focused approach was identified to add to the credibility of this study, namely 'Key Incident Analysis' which makes it possible to study particular practices of a social group, without performing an extensive ethnographic study (Green & Bloom, 1997). This study focused on particular instances/activity for integration which may have happened in the classroom, initiated by the teacher or students, or which happened in the normal course of designing and making the product. Key incident analysis also plays an important role as a specific means of data reduction for analysis and interpretation. As observed by Green and Bloom:

> [T]he ethnographer identifies key events or incidents (e.g., recurrent events, events that have sustaining influence); describes these events or incidents in functional and relational terms; explores links to other incidents, events, phenomena, or theoretical constructs; places the events in relation to other events or to wider social contexts; and then constructs a description so, that others may see what members of a social group, need to know, produce, understand, interpret and produce to participate in appropriate ways. (p. 186)

This comment seems to be consistent with the thoughts of Wilcox (1980), regarding the emergence of the development of REAA (Reconstructive Ethnographic Account Approach). Wilson observed the work of Erickson (1977) and noted:

> The ‘key incident’ approach (...) involves the analysis of qualitative data in which incidents or events have been recorded in extensive descriptive detail. Analysis of the data leads the researcher to focus on certain incidents as key incidents, or concrete instances of the working of abstract principles of social organization. As Erickson (1977) summarizes, 'This involves pulling out from field notes a key incident, linking it to other incidents, phenomena, and theoretical constructs, and writing it up so others can see the generic in the particular, the universal in the concrete, the relation between part and whole' (p.??). Erickson notes that the key incident approach may involve massive leaps of inference over many different kinds of data from different sources, including field notes, documents, elicited texts, demographic information, unstructured interviews, and so on. (Wilcox, 1980, p. 9)

It is essential at this stage to define the term ‘key incident’ used by Wilcox (1980). “A key incident is key in that it represents concrete instances of the working of abstract principles of social organization” (p. 9). This approach has implications for the research as key actions taken by the teacher and students in the technology classroom/workshop will be considered to assign meaning to their actions to generate a broader meaning in terms of integration, in addition to the classroom observations, social actions, practices and their written technology portfolios will also form a key element of the data analysis. All instances of classroom conversations with the teacher and the students have been recorded and an interpretative commentary has been summarised to create a ‘particular description’, which is considered by Erickson (1985) to be an essential core of a report of fieldwork research.

Key incident analysis is a central part to this research due to its reconstructive nature. The approach is reconstructive in as far as the result is a collaborative reconstruction of the social reality (practices and perceptions) of the participants, on the basis of which the participants are being able to reconstruct their reality in ways they were not aware of before. The next chapter will present some key events from this case study and the reality constructed on the basis on the observations, interviews, conversations, questionnaires and portfolios which will help to understand the complex nature of classroom integration of science, mathematics and technology by the participants.

3.9.3 Discovery

Integration of science and mathematics in a technology classroom is not readily identifiable unless done purposefully. This requires a detailed analysis of a technology classroom to observe how the teacher and students participate and collaborate to design a product. The integration of science, mathematics and technology was experienced by the various participants and their opinions were recorded. Instances where integration of science, mathematics and technology took place were analysed using the hermeneutic and key incident analyses which led to the discovery of various themes and sub-themes. Thus, in the process of the analysis and interpretation, agreements, contradictions which were in the form of constraints, frustrations and misconceptions were also considered and illustrated in the findings and discussion chapters of this thesis.

All classroom observation field notes, interview transcripts, portfolios and pictures were imported into NVivo, the qualitative data management tool. In order to gain a complete understanding of the integration of science, mathematics and technology, the researcher took into consideration participant views on integration, the researcher's own observation notes, and photographs and scanned student portfolios for the analysis of relevant data. Then relevant units of data were selected and coded according to the elements of the literature review as discussed in Chapter 2. Under each element, there were several sub-themes. During the analysis process some of these sub-themes were merged or discarded based on how significant they became in answering the research questions. This rendered the process dynamic over time. Later, some extracts of the transcribed interviews were incorporated as quotations in this thesis to help support the understanding of the integration of science, mathematics and technology in a design context. Over the analysis process using the hermeneutic approach and key incident analysis, the data were studied to derive sub-themes which were reconsidered based on how significant they became in answering the research question. Examining the data in a social constructivism and socio cultural context allowed this study to develop understandings of the complexities, relationships and mediations that existed within the classroom. As a method of triangulation, the observation field notes, photographs and scanned student portfolios were also imported into Nvivo, coded and categorized according to sub-themes developed based on the literature and the conceptual framework.

Analysing focus group interviews, informal discussions and teacher interviews was challenging since the collected data were vast. The field observation was carried out on a daily basis to capture the researcher's perception of the integration that was taking place in the classroom. Participants' experiences gathered via interviews and discussions (formal and informal) were incorporated in answering the research question.

The discovery process of searching reliable and sensible data, together with the hermeneutic approach and key incident analysis process, entailed a search for the important meanings in what people said in interviews, discussions, what was observed, and what was found in documents. Maykut and Morehouse (1994) suggested asking the following questions to determine prominent patterns:

1. What are the recurring words, phrases, and topics in the data?
2. What are the concepts that the interviewees use to capture what they say or do?
3. Can you think of other concepts that capture some recurring phenomenon in the data, that help sensitize you to recognize it when it occurs again? and
4. Can you identify any emerging domains in your data, expressed as a phrase, proposition or question? Do you see any patterns? (p.44)

The categorized units of meaning were examined with the preceding questions in mind and then compared with incidents of interest which took place in the classroom and the perceptions of the students and the teacher. One of the challenges of qualitative research is how the researcher can make sure the results of the inquiry are trustworthy, which involves the use of a set of criteria for assessing the quality and adequacy of the qualitative analysis. For this research, I will consider factors such as transferability, credibility, conformability and dependability to make the study trustworthy. These concepts are now examined in relation to this study in more detail.

3.10 Ensuring Trustworthiness of the Study

One of the challenges of qualitative research is how the researcher can ensure the results of the inquiry are trustworthy (Halldórsson & Aastrup, 2003; Lincoln & Guba, 1985). The qualitative criteria of trustworthiness are discussed in detail in the coming sections.

3.10.1 Credibility

The issue of trustworthiness is central to the acceptance and appreciation of such interpretive studies. Lincoln and Guba (2000) discuss four concepts of trustworthiness under the banner of 'truth values.' The first concept is that of credibility which corresponds to the concept of internal validity, which is rejected on the basis that there are multiple realities in a given situation, whereas a single reality is implicit in experimental designs that utilise such concepts of validity. The researcher will adhere to the techniques suggested by Lincoln and Guba (1985) to help ensure credibility: prolonged field; persistent observation; debriefing by peers and supervisors; and a literature review.

- *Prolonged field engagement* to understand factors that might affect credibility of results such as culture, testing possible distortions by students and also building the trust with students.
- *Persistent observation* where the purpose is to learn and identify characteristics and elements that are most important for integration and obtaining detailed information.
- *Debriefing by peers and supervisors* which will allow proper evaluation of the quality and authenticity of research interpretations.
- *Literature review* to compare/contrast the researcher's prior beliefs as he encounters the instances.

To understand the meaning of truth value, the researcher must demonstrate multiple constructions of reality adequately. The credibility of this study will be considered to be enhanced through these methods outlined by Lincoln and Guba (1985) above. The study continued for ten months which allowed the development of relationships between the participants (teacher and students) encouraged a meaningful reflection on observations and practices. The possibility of transferability of this study was ensured by collecting adequate data in detail for the problem under investigation, and triangulating the data of the study. Credibility was also achieved through peer reviewing and debriefing regularly with the supervisors and through conference presentations.

In this case study, evidence was collected mainly by classroom observations, field notes, and interviews with students and teachers. In the classroom, the researcher was prepared to have a sense of reality about the situation being researched, was focussed on good communication, and behaved in a way which enabled access, empathy, rapport and trust with diversity of participants. In establishing rapport with research participants, the researcher strived positively to build trust to enable a relationship to be established that would lead to the sharing of insightful data, while at the same time ensuring respect was maintained between researcher and participant.

Member checks were performed, where surface level interpretations were tested with the research participants from whom the data were originally collected. This process adds to the authenticity of research (Guba & Lincoln, 2005).

3.10.2 Transferability

Transferability refers to the degree to which the results of qualitative research can be generalized to transfer to other contexts or settings. The responsibility in determining applicability lies with others apart from the researcher. As indicated by Marshall and Rossman (1995), it is possible by referring back to the original theoretical parameters to "determine whether or not the cases described can be generalised for new research policy and transferred to other settings" (p. 144). It is clear that the responsibility of the researcher in this context is to provide sufficient descriptive data to enable logical judgements (Lincoln & Guba, 1985).

Efforts to ensure transferability included collecting adequate data in detail for the problem under investigation, detailed descriptions of the observations and context to assist in the investigation of integration.

3.10.3 Dependability

Dependability in qualitative inquiry is achieved through observation over time and explanation of change. Extended observation and explanation of social change also helps to establish the dependability of study. Another conception of dependability is based on the inquirer considering factors that contribute to instability within a phenomenon (integration), as well as factors induced by the design of the study.

The dependability of this study will be established if the credibility is reasonably established (Lincoln & Guba, 1985). The dependability of this study was addressed through the process utilised for extensive data collection, refinement and retrieval. Various authors suggest that auditing can be a key method in achieving dependability. Bryman (2012) suggests that it is vital to keep complete records of the research process by forming a research question, selecting participants, writing field notes, interviewing, transcribing and analysing data. An audit trail in a qualitative study "describes in detail how the data were collected, how categories were derived, and how decisions were made throughout the inquiry" (Merriam, 2002, p. 27).

The classroom observation field notes, portfolios, pictures, questionnaires, and audio recordings of the interviews have been saved in virtual formats and stored in the qualitative data management tool, NVivo. Earlier drafts of research analysis, chapters, information and consent letters and ethical approval documents have also been saved in virtual formats and stored in separate folders on the researcher's personal computer.

The coding of data using NVivo involved the identification of the coding themes that were informed by the literature review and the conceptual framework adopted for this study. The coding process was enacted by compiling a list of codes (codebook) corresponding to appropriate themes and judging for each predetermined segment of text whether a specific code was present. This procedure is standard in qualitative data analysis, although assessing the degree to which coders can agree on codes (intercoder reliability) is a contested part of this process (Armstrong et al., 1997; Mays & Pope, 2000). This study considers intercoder reliability as a useful concept in settings characterized by applied, multidisciplinary, or team-based work (Armstrong et al., 1997; Boyatzis, 1998; Carey, Morgan, & Oxtoby, 1996; General Accounting Office [GAO], 1991; Gorden, 1992; Krippendorff, 1980; MacQueen, McLelland, Kay & Milstein, 1998; Miles & Huberman, 1994; Weber, 1990). This study established an intercoder reliability in an attempt to reduce the error and bias generated when the researcher (unconsciously) takes shortcuts when processing the voluminous amount of text-based data generated by the data collection tools. The two raters were recruited on the basis of their background in technology education and science education. One of the raters was a Lecture in Technology Education in New Zealand and the other rater was a fellow research student with a science education (physics) background. One of the classroom field observations and two scanned pages from a student portfolio was inter-coded by two research colleagues to determine inter-rater reliability. Inter-rater reliability (using Cohen's Kappa coefficient) is the degree to which independent observers show agreement in their observations (Fleiss, Levin, & Paik, 2003). Inter-rater agreement is a measure of consistency that assesses the agreement of observations made by two or more raters or judges (Vanbelle and Albert, 2009a).

One colleague was pursuing his research in the field of technology education and the other colleague in the field of science education. The field observation and portfolio documents were chosen randomly by the researcher and his two colleagues coded the documents using Nvivo 10 in their own time in two different locations. The intercoder agreement came out to be more than 97 % for almost all the codes. A low intercoder reliability (76%) came for one code which the rater with science background was not aware of the meaning in technology context. The inter-coder agreement is displayed in Appendix F. The appendix displays the pseudonyms of one of the coders (RE) along with the codes, nodes, frequency of codes for each coder, and the inter-coder agreement which came to be 90 percent and more for most of the codes.

3.10.4 Conformability

Conformability of qualitative inquiry is achieved through an 'audit trail', which allows the researcher to account for all the decision and activities by showing how data were collected, recorded and analysed. The data will be analysed by keeping in mind the key question being whether or not "the data help confirm the general findings and lead to the implications" (Marshall & Rossman, 1995, p. 145).

The researcher also used the reflective journal, a "kind of diary in which the investigator on a daily basis, or as needed, records a variety of information about self (hence the term 'reflexive') and method" (Marshall & Rossman, 1995, p. 327, parentheses in original), to supplement the researcher's observations on a daily basis, to interpret and plan data collection. The e-blog/reflective journal maintained by the researcher included reflections on the daily findings as they developed throughout the day, week and the school term.

The examination of the emergent themes and issues was integral to the understanding of integration in a technology classroom while designing and making a product. These themes and issues emerged as the study progressed, although, initially, the literature provided some guidelines. Themes and issues were used to construct theme aspects such as commonalities, uniqueness and contradictions as indicated by Lidstone (1999). In this manner the data were analysed and recontextualised so that it had meaning as a whole entity, and not as a series of unconnected experiences.

While analysing the data, I also recorded my personal views in the form of memos in Nvivo. I referred to those memos when I was writing up my findings and discussion chapters. This reflective process helped confirm the credibility, triangulations, reliability and confirmability of my research.

3.11 Ethical Issues

As this research involved observations, communication and collaboration with human subjects in organisational terms, a number of ethical issues were identified and addressed. The first was the competence of the researcher which needs to be considered before commencing the research (Miles & Huberman, 1994). The researcher had gained enough experience through work and educational contexts in the area to be investigated (secondary technology education), while the supervisors of the researcher are highly experienced in the field of technology, which improved the competence of the researcher.

Informed consent is a key aspect of ethical research and Appendix A outlines all the steps that were taken to ensure that all participants (principal, teacher, students and their guardians) gave informed consent to the research.

The benefit to the participants was considered for this research as this study would provide an evaluation of the teacher's teaching, and feedback from the students which would help the teacher to cater to their needs for better learning and understanding. The benefit to the participants was also considered as a part of this research such that they would maintain a positive commitment towards participation and cooperation for beneficial outcomes of the research. The benefit for the teacher involved developing cross disciplinary content knowledge for integration with regards to the luge context, planning resources and materials, professional development, seminar invitations and providing a sound input to researchers and having an extra personnel (researcher) to work with him at times. The benefit to the students came in the form of motivation and interest from working in designing and making a product and seeing the importance of their input for the study

A major aspect that may attend any research programme is the risk of personal harm and reputation. The main risk is through research publications where the participants may be recognised and feel criticized, demeaned and condemned. Participants were, therefore, informed beforehand about the use of pseudonyms and that any ideas and thoughts provided would be used to improve the current situation which will provide better understanding. Participants were also encouraged to examine their own interpretations of data collected, which minimised the risk of unexpected conclusions being drawn or interpreted. Parameters for negotiations were considered as outlined by Guba and Lincoln (2005) in their discussions regarding authenticity and fairness.

The ownership and control of the collected data was also examined before the research commenced. The analysis and conclusions drawn from the study rested primarily with the researcher, as was recognised by the participants. Participants were informed about their access to the data which concerned themselves, and their right to comment on the conclusions derived and to make any appropriate changes in the data derived from their input.

The researcher also evaluated situations and considered the degree to which he may have to intervene in particular situations in the classroom or workshop ensuring his intervening did not disrupt the classroom learning. The role shift as a researcher and a facilitator took place during this project thereby abiding by the professional standards expected of an academic.

3.12 Presenting the Results

The emphasis of narrative analysis is on the stories people tell (Merriam, 1998). Merriam indicated that one of the strengths of thinking about data as narrative is that it opens up the possibilities for a variety of analytic strategies. Employing description and direct quotes from the participants, this report presents to its audience, those who are interested in understanding how the integration of science, mathematics and technology takes place in a technology classroom, through a comparative analysis of qualitative data in the forms of observations, interviews, discussions and document analysis.

Chapters 4, 5 and 6 are a presentation of findings obtained through the field observations, teacher and student interviews, and a review of the technology portfolios of the students. This section of the study also contains a description of the participants and a narrative summary of the major domains that emerged from the triangulated data collected from the technology classroom and workshop. The constant comparative method (Maykut & Morehouse, 1994) is used to present the data results. The basic strategy of this method is to constantly compare the meaning of the data. Using data recorded in transcripts of field observations, interviews (individual and focus groups), discussions and student portfolios, the researcher compared words, noted observations, and analysed student records, first by analysing the field observations and then comparing these with individual cases. These comparisons led to possible explanations of how students and teachers integrate science, mathematics and technology while working on a technological design context. The various categories of knowledge derived were then unitized to determine any similarities found in the research literature. Finally, documents from the case were analysed and compared to the data collected from individual participants to gauge how well teaching strategies and practices influenced integration of knowledge in designing and problem solving in the design context.

Chapter 7 provides a defence of the evidence presented related to the investigation of integration in a technology classroom in addition to the strategies/practices implemented to address the needs of students to complete the design successfully. Chapter 8 includes conclusions drawn from the study, implications and recommendations for STEM educators and technology teachers to implement an integrative learning environment, and recommendations for further research.

3.13 Summary of Chapter

This chapter has presented the research methodology, and the theoretical and methodological underpinnings of the research. It concluded that an interpretive case study design was appropriate to address the aim and objective of the research. The collection and analysis of data was outlined, and the issues that needed to be considered in relation to credibility, transferability, dependability and confirmability and ethical issues associated with the research were addressed.

Chapter 4 presents the findings in a chronological order.

CHAPTER 4. STAGE 1: DESIGN BEFORE CONSTRUCTION

4. 0 Initial Investigations

In order to provide a context for the presentation of data, the mode of data presentation and the contact experiences between teacher and the students are presented and explained in narrative form. A chronology of events is presented in various stages from Term 1 to Term 4 with interpretations of this data in terms of the integration of science, mathematics and technology. Presenting the data in this format will help the reader to understand the case as the students engaged in the design process. The purpose of the introduction to this chapter is thus to contextualise the data that is to be presented in subsequent sections.

4.1 Introduction

The purpose of this study is to analyse the data from observations, interviews, portfolios and questionnaires to answer the research questions and to improve the teaching practices in an integrated STM environment, by observing the pedagogy of the teacher and the practices of the students in a technology classroom. Data was collected to develop an understanding of the integration of science, mathematics and technology by observing practices of students and the teacher in a technology classroom. The qualitative data will reveal the categories of knowledge (science, mathematics and technology) used by the students while working in a design context.

The classroom observation was conducted four times a week during the technology class (Year 11) over a period of 10 months (Feb 2013-Dec 2013) at a school in Hamilton. A full time technology teacher (male) with 20 years of teaching experience and 19 of his students (male) were recruited for this study. The teacher and his students were informed about the goals of the research at the beginning of Term 1 and informed consent letters were distributed and collected during the first week of the study. The researcher collected data throughout the year and the classroom observations enabled the researcher to see how students integrate maths, science and technology and whether the integration process occurs naturally when students design and make products. Teacher interventions to purposefully integrate, any diffusion of cross-disciplinary knowledge, and prior knowledge students brought to the classroom to solve the problems was identified.

The technology area in which this class worked consisted of a design room and a workshop. The design room was equipped with tables and chairs, projectors, a whiteboard and 10 desktop computers for the students to share. The workshop included the required accessories, materials, tools, machinery and equipment for making the luge. There was enough space in the workshop for the 19 students to work without space congestion.

The strategy planned by the teacher during Term 1 was to develop students' ideas and strategies on building a luge in a constructive learning environment. The teacher also wanted to integrate science and mathematics into this project as he wanted to provide an integrated learning environment and also to make students realise the cross curricular links in technology as he believed it is important to do so.

The findings in the following chapters are organized into the stages of the project. The students initially spent most of their time designing in the design room, then moved to the workshop to make the product. There was continual movement by the students between the workshop and the design room when the need for research or direction to the class was identified by the teacher. The first stage of the findings present the role of the teacher in introducing the students to the context of the luge in Term 1, the practices of the teacher and the students, their perceptions of and engagement in the classroom. The second stage (Chapter 5) will report findings from Term 2 and Term 3 collectively which was mainly the making stage of the project, and the final stage (Chapter 6) in Term 4 presents the evaluation and testing of the luges, the student focus group interview and teacher interview data, with a detailed focus on the science and mathematics identified by the students during the various stages.

Before presenting the findings of the design stage, a summary of the data from the questionnaire which was introduced at the beginning of the study will be presented as it is useful to understand the perceptions and attitudes of the students and the school subjects they anticipate will be useful in completing their luge design.

4.2 Technology in Year 11- Attitude, Motivation and Experience

The initial questionnaire was introduced at the beginning of Term 1 with the purpose of capturing the perceptions and interests of the students taking technology in Year

11. The researcher was invited by the teacher to provide instructions and to distribute the questionnaires to the students in the classroom. The findings from the questionnaires are briefly presented in the following paragraphs.

In general, the students of this class were motivated to take technology as it was something meaningful and personal to them. Some students thought it was fun and felt self-fulfilled/satisfied when they were in a technology classroom as they enjoyed designing and making products. Many students indicated that they took technology because they like building/making/developing things and further, they thought the subject will help them develop skills to become an apprentice, an engineer or a trades-person in the future. All indicated that they have taken technology classes in previous years and found it to be an enjoyable subject. One student indicated that there are various skills that he thought he would develop and improve in a technology classroom which seemed more beneficial to him than other subjects.

Technology was identified as an interesting subject for a variety of reasons, the most common of them being to make things in the classroom with different materials and to learn new knowledge and skills which are applicable to real life. Students also mentioned that the various aspects of a design process like planning, material manipulation and time management, along with hands-on activities, added to their interest in technology. One student hoped that he would learn a lot about physics in the technology classroom. The teacher was also considered to be a reason for the subject to be interesting as he explained all aspects of the design task in detail and made sure that the students understood the context.

All 19 students said they had previous experience of designing and making as they had taken technology in the past and had worked on the project of designing and making scooters as part of the technology curriculum in Year 10. The students brought in the knowledge of process and techniques (procedural knowledge), mainly regarding materials and the ways to manipulate them to make fit for purpose products. The aim of the 2007 Technology Curriculum in New Zealand is to increase the critical thinking skills through technology programes with a focus on design with could make students to peform in-depth thinking. The previous technology projects students have undertaken in previous years provided them skills and experience to work with materials under the guided supervision of a teacher since the context of designing was different in Year 11 than the previous years. Students brought previously developed skills and knowledge to the designing and constructing of the luges in Year 11. The raw data from the questionnaire is presented in Appendix C (Table C1) which highlights the skills and knowledge students brough in Year 11 from previous technology years.

The next section presents the findings from Stage 1 (Feb 2013- April 2013) which was focussed on the design of luges through analysis of functioning components, testing and selecting materials and appropriate processes involved in constructing the luges.

4.3 Stage 1- Designing the Luge

This section reports the data obtained from the classroom observations and recordings, teacher interviews, questionnaires and student portfolios to provide a chronological account of the context and activities in Stage 1 during which the teacher, students and stakeholders interacted with each other, materials, resources, tools and the design environment to design their luges. Stakeholders were mainly participants, other than the designer itself, outside the project who would be driving the luge. The stakeholders were involved in this project by the teacher to make the project compelling and more relevant.

The term started with the teacher greeting and welcoming the students and introducing them to the project they were required to construct that year. An outline of the various phases of the project was presented to the students. The next section will present the first stage of testing and investigation performed by the class: the *momentum testing* phase.

4.3.1 Momentum Testing

The teacher started the stage by introducing the concepts of momentum and gravity, which enable the luge to move. The goal in designing and making the luge was to generate the optimal speed when raced down an inclined track. Students were expected to take part in a race at the end of the year with two other local schools in Hamilton. The purpose was to motivate students to design a luge with speed and performance as the main criteria. The teacher outlined these to the class:

> The idea of the luge is to get the maximum speed. Everybody has the same force applied to the luge (i.e., gravity), so the same size engine, and there are a few things that are going to affect the speed of our luge like the mass [pilot], wheel size and friction. (Teacher, Classroom Recording)

The teacher instructed the students to perform experiments initially to develop an understanding of the relationship between the speed of the luge with respect to various wheel sizes, and the weight of the pilot. The requirement was to investigate whether the combined weight of the pilot and luge and the size of the wheel set had any effect on the speed of the luge. This aspect of the project during Term 1 was ‘the momentum testing’ phase, where investigations were performed, with the appropriate controls, measuring the variables (weight of the pilot and wheel sizes) which affect the speed of the luge. A previously constructed luge was utilised for the purpose of carrying out the investigations. The momentum testing phase was conducted outside the classroom premises on a road with some gradient. In the first test, the same pilot was allowed to test three different wheel diameter sizes (50mm, 70mm and 100mm diameter) to conclude which provided a stable and smoother ride. The width of the wheels (surface contact width) was not known and recorded by the researcher. The width of the wheels was different for the three wheels. The 70 mm diameter wheels had the maximum surface contact width. The measurements for the width of the wheels are not precisely known but the 70mm diameter wheels were the widest followed by the 50 mm diameter and 100 mm wheel diameter. The wheel sets were different in diameters and in width or the area of contact with the ground, hence it cannot be said to be a perfect investigation as some variables were not constant. Three sets of readings from three runs of the luge were taken by the teacher and noted by the students. The second test involved a 70mm diameter luge wheel with two different drivers (45kg and 110kg in weight) to determine what combination would provide optimum speed for the luge over the set distance trial. Two sets of readings were taken for each test to select the best wheel size and to investigate the effect of different pilot weights on the 70mm diameter wheel.

Students recorded the data from the field trials then discussed those results in the design room, which gave an opportunity to think about and reflect on their field observations. The teacher triggered some discussions in the classroom around the wheel size and the time they took to cover the same distance during the same trail test conditions. The concepts of circumference of wheel in relation to revolutions were discussed. The teacher was trying to make students think critically regarding the wheel sizes and speed and the students were expected to make logical conclusions based upon the available data.

In subsequent sessions, the teacher provided time for the students to write explanations, justification and conclusions for this testing phase. He provided an outline to the students on how data and explanations should be presented. The teacher mentioned that the language of the explanation was to be kept simple and understandable so that any non-expert outside the field of technology should be able to comprehend their justification.

Classroom discussions were initiated by the teacher to encourage students to reflect on the data. These discussions involved the use of information from science and mathematics, which was not purposely introduced by the teacher, but naturally developed in the course of student conversations while trying to understand and explain the observed phenomenon, as it is illustrated by the excerpt below:

T: Just try to think about the bigger wheels, think what they do while going down the driveway. Why do you think they go faster [take less time] than the small ones?

S 1: bigger wheels roll faster

S 2: and cover more distance

S 3: less resistance on them

T: Are they doing the same amount of revolutions as the little one?

S 1: no..?

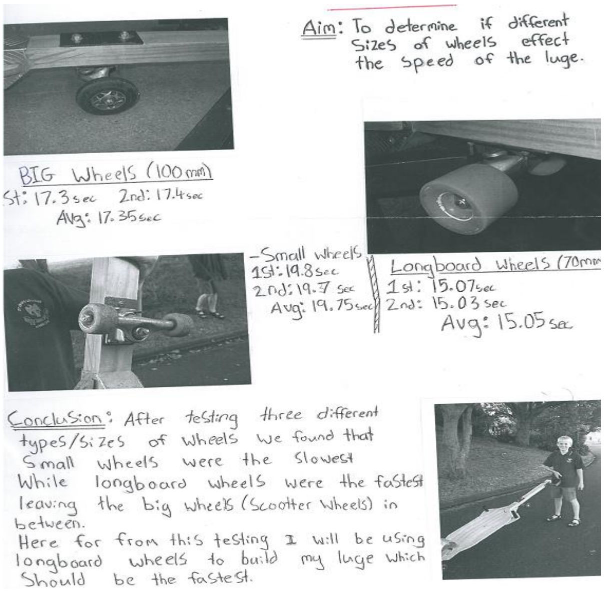
T: While doing a revolution do they cover more distance? Is that what it is or they do less revolution and cover more distance? Think about these mountain bikes, why do they have bigger wheels? Does the circumference of the wheel have anything to do with the distance travelled then?

S 2: Yes, so they can go through rocks and stones easily

T: So, they can go over terrain they are designed to better work on. You know they don't get caught; they actually go over them, so I kind of believe that the bigger wheels have their effect as well. Now the circumference means something else doesn't it, it means the distance it will cover or travel in one revolution.

The prior knowledge from science and mathematics and the everyday knowledge of students was recalled so they could relate it to the current situation. The technological context of testing wheels through a practical driving experience gave the teacher an opportunity to discuss the findings which resulted in recalling knowledge from science, such as circumference, revolution, resistance and their effect on the speed as evident from the portfolios in Figure 4.1 (a), (b) and (c).

Classroom discussion was also initiated by a student (JS) relating to the relationship between the width of the wheels and speed of the luge. However, not all students seemed interested in the conceptual question initiated by JS and started working on their own, ignoring the discussion. The concept of the distribution of the weight of the pilot to the ground through the width of the wheel was briefly discussed and reflected in the portfolio of the student as seen in Figure 4.1(d). This indicates to some extent that not all students felt this information relevant to be included in their portfolio and neither did the teacher advise students to explain the result in the conclusion sections. Students were provided time to present their evidence, findings and conclusions in their portfolios.



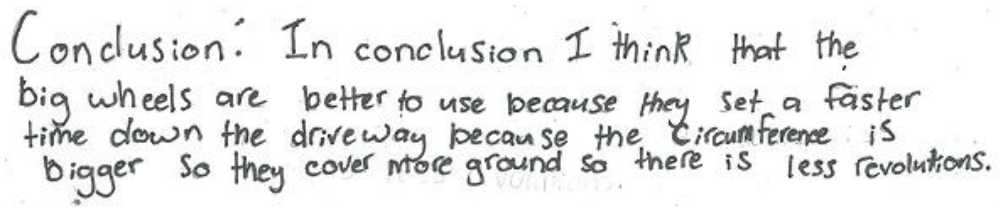
Aim: To determine if different Sizes of wheels effect the speed of the luge.

BIG Wheels (100mm)
St: 17.3sec 2nd: 17.4sec
Avg: 17.35sec

-Small wheels
1St: 19.8sec
2nd: 19.7 sec
Avg: 19.75sec

Longboard Wheels (70mm
1st: 15.07sec
2nd: 15.03 sec
Avg: 15.05sec

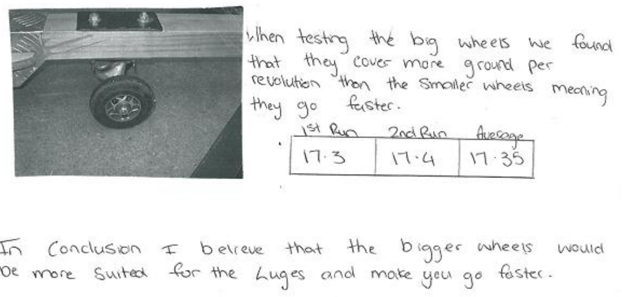
Conclusion: After testing three different types/sizes of wheels we found that Small wheels were the slowest While longboard wheels were the fastest leaving the big wheels (Scootter Wheels) in between.
Here for from this testing I will be using longboard wheels to build my luge which Should be the fastest.



Conclusion: In conclusion I think that the big wheels are better to use because they set a faster time down the driveway because the circumference is bigger So they cover more ground so there is less revolutions.

(a)

(b)

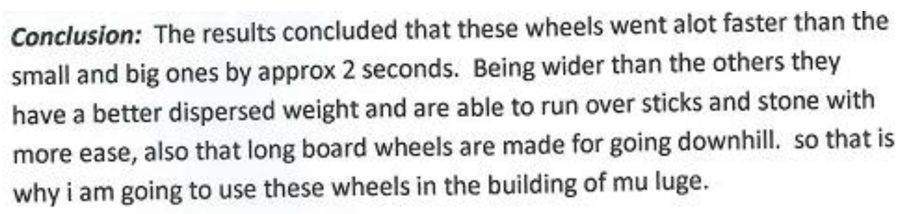


When testing the big wheels we found that they cover more ground per revolution than the smaller wheels meaning they go faster.

1st Run	2nd Run	Average
17·3	17·4	17·35

In Conclusion I believe that the bigger wheels would be more suited for the Luges and make you go faster.

(c)



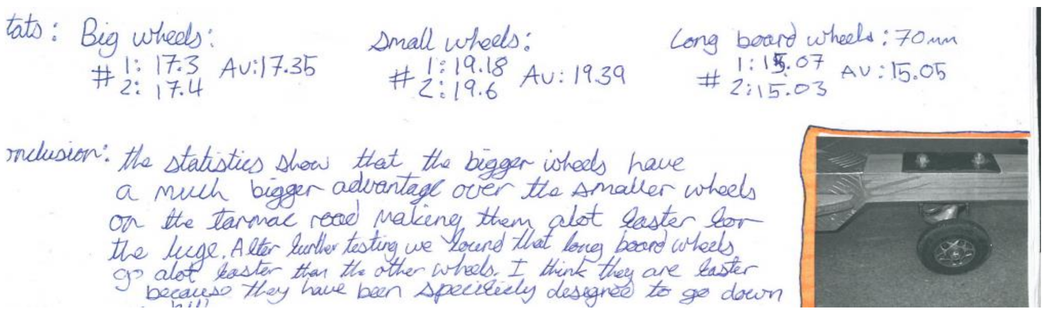
Conclusion: The results concluded that these wheels went alot faster than the small and big ones by approx 2 seconds. Being wider than the others they have a better dispersed weight and are able to run over sticks and stone with more ease, also that long board wheels are made for going downhill. so that is why i am going to use these wheels in the building of mu luge.

(d)

Figure 4.1 (a), (b), (c) and (d) shows some conclusions derived by students in their technology portfolios after the momentum testing phase.

Students concluded that wider wheels (70mm diameter wheels rather than 50mm and 100mm diameters) were the fastest and took an average of 15.05 seconds to reach the finish as compared to the bigger (100mm diameter) and smaller (50mm diameter) wheels as indicated in Figure 4.2. There was also no evidence of scientific concepts being utilised in the explanation of the observed phenomenon. Evidence from the portfolio in Figure 4.1(d) also shows the concept of the weight being dispersed from the wider wheels (70 mm diameter) compared to the small (50mm diameter) and bigger wheels (100mm diameter) which took an average time of 19.39 seconds and 17.35 seconds respectively to complete the run. The student attributed to the grip and better weight dispersed to the ground through the wider (70mm diameter) wheels for the speed of the wheels. The data from Figure 4.2 also indicates that this student believed that the 70mm diameter wheels were specifically designed to go downhill.

The theme developed from the data in the portfolios is that the bigger wheels (100mm diameter) were faster and took less time than the smaller wheels (50mm). The longboard wheels (70mm diameter) provided a much faster and smoother ride compared to the other two wheel sets. This can be attributed to 70mm diameter longboard wheels being much wider and providing more contact with the ground than the 100mm and 50mm diameter wheels. The results were tabulated and averaged by the students after the test trails with appropriate justification of their observations. There was also evidence in their portfolios regarding the concept of distance covered and the number of revolutions of the wheels. Students mentioned that longboard wheels are faster as they are specifically designed to go down hills. Students in this classroom chose to use the longboard wheels in their project based upon their experimentation and conclusions.


tats: Big wheels: # 1: 17.3 2: 17.4 Av: 17.35
Small wheels: # 1: 19.18 2: 19.6 Av: 19.39
Long board wheels: 70mm # 1: 15.07 2: 15.03 Av: 15.05

nclusion: the statistics show that the bigger wheels have a much bigger advantage over the smaller wheels on the tarmac road making them alot faster for the luge. After further testing we found that long board wheels go alot faster than the other wheels. I think they are faster because they have been specifically designed to go down

Figure 4.2 Conclusions derived by a student based upon the available data on the 70mm longboard wheels.

Figure 4.2 also indicates that the 70mm diameter wheels perform better in terms of speed but there is no speculation or explanation by the student of why this might be the case. The student mentioned that the 70mm diameter wheels are specifically designed for speed without much explanation. This may indicate that the available data from the test trails informed the choices students made to select the best wheels for their luge. The prior knowledge of longboard wheels being designed for speed was brought in in this classroom which may have resulted in choosing the wheels without any detailed explanation of why. This may also indicate that practical and prior knowledge may discourage the students from initiating discussions or considering the details behind their choices. Students knew the 70 mm diameter longboard wheels were designed for speed and brought this common perception into the classroom which prevented them from further questioning the collected data.

Conclusions were also developed by the students in their portfolios regarding the relationship between the weight of the pilots and speed. The most common conclusion was that the heavier pilot is faster than the lighter pilot, as seen in Figure 4.3. Two test runs were performed on an already constructed luge with the chosen 70mm diameter wheel. The two test pilots weighing 45kg and 110 kg were selected to test the effect of their weights on the speed of the luge. Two test runs with each pilot were performed and the data was recorded as seen in Figure 4.4. The notes from the student portfolios highlight the level of investigation performed to formulate conclusions based on some basic tabulation and mathematical calculations. Few students apart from the above mentioned example (Figure 4.4) also mentioned that the difference between the readings obtained for the heavier and lighter pilot was minimal, both the pilots took nearly the same time to complete the trial run, as seen in Figure 4.4. This indicates the practical misalignment between the observations made by the students during the investigation and abstract science behind their observation. The variance in the readings included a lag in the self-initiated push of the luges by the pilots. The heavier pilot propelled his luge faster than the lighter pilot and these variables affected the recorded readings. As observed, students communicated their findings based on their practical experience as perceived by them which was co-constructed through their observations and investigations in the design environment. They did not find it significant to use information like inclined planes and motion from science to explain such a difference in the readings.

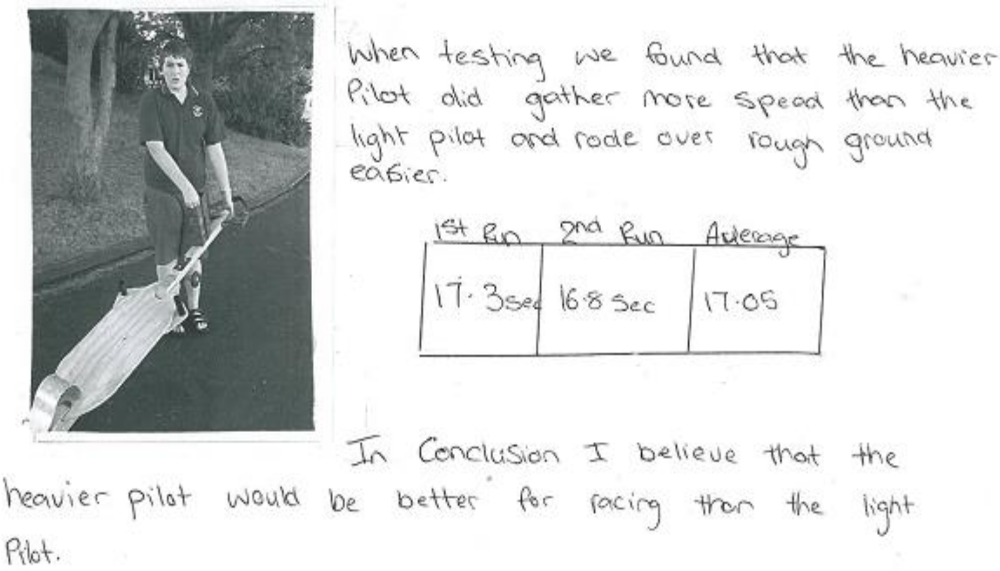


Figure 4.3 Conclusions drawn by students in the technology portfolios from momentum testing phase.

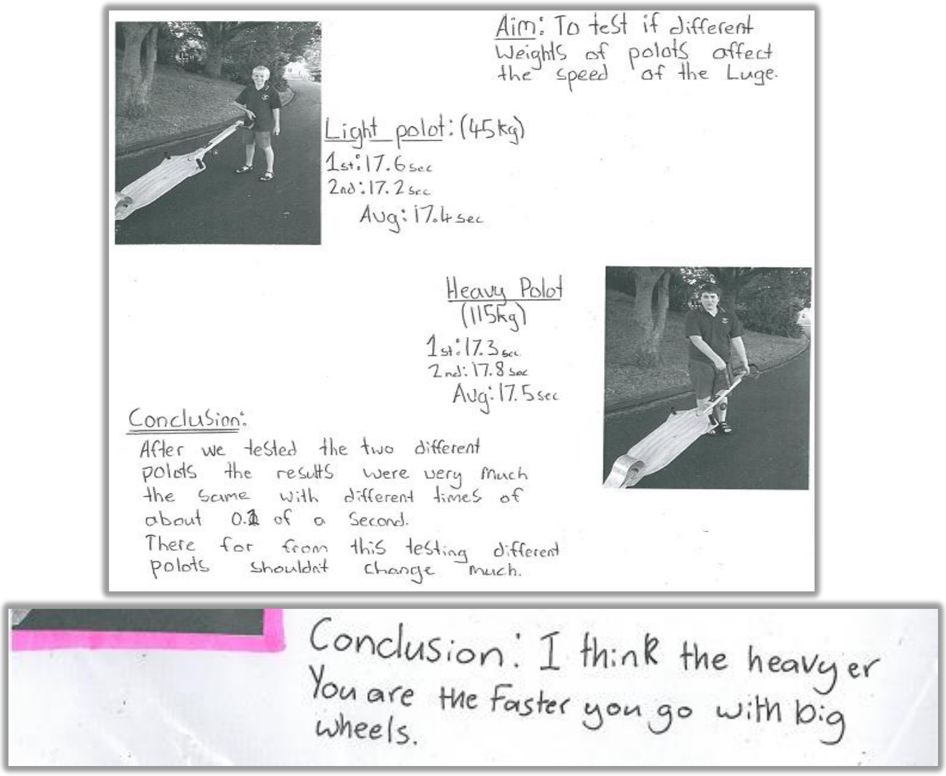


Figure 4.4 Conclusions drawn by two different students in the technology portfolios from momentum testing phase.

Students did not attempt to explain the reasoning behind their observation when they developed the common conclusion of ‘heavier goes faster’. This reflects, to some extent, that the knowledge derived from observations and investigations was considered enough to proceed in technology by the teacher and his students since it is a practical affirmation. The tacit knowledge of investigations in technology encourages students to conclude based upon their findings. The conclusions derived were based upon the available data collected rather than providing a detailed explanation rationale for a choice.

4.3.2 Luge Research

The rationale for conducting the luge research was to provide an opportunity to observe and learn about the current ‘state of the art’ luges and to identify the functioning of the components, materials they are made of and the processes involved in construction. This would help the students to choose their own design and the materials required for their luge. As the teacher noted in an informal conversation with the researcher after a session:

> Once you start to understand how the things work by looking at the components and materials and you have got the ability to make decisions whether you are going to purchase this one or the other one or whatever. So it’s really handy. (Teacher Discussion, Term 1)

The teacher also indicated that it may motivate the students as it gives them a chance to observe the latest designs, and a range of examples will broaden their understanding of materials and components while designing and making their luges.

The teacher instructed the students to have a look at the different types of luges and select those that interested them from the internet. Students proceeded to search on the computers in the design room. Each computer was shared among two or three students during this phase. The teacher explained how to clearly write down the information so they could present their research in their technology portfolios. Students started their research on luges while the researcher had a conversation with a few students during this phase. In their conversations the students used terminology like ‘streamlined’ which related to scientific knowledge from aerodynamics, so while they may not use scientific terminology they may have a broader understanding of the idea behind the terminologies.

The classroom conversation indicates that the understanding of streamlined and lighter luges for optimum speed was present during this phase. This also indicates that students were referring to making their luge aerodynamic and structurally sound, built for optimal speed. Students were observing the latest designs and getting an idea of the positioning of the components and shapes of the luge. This may have an influence on their design in terms of material selection and processes as indicated by the. Evidence from their portfolios is presented in Figure 4.5.

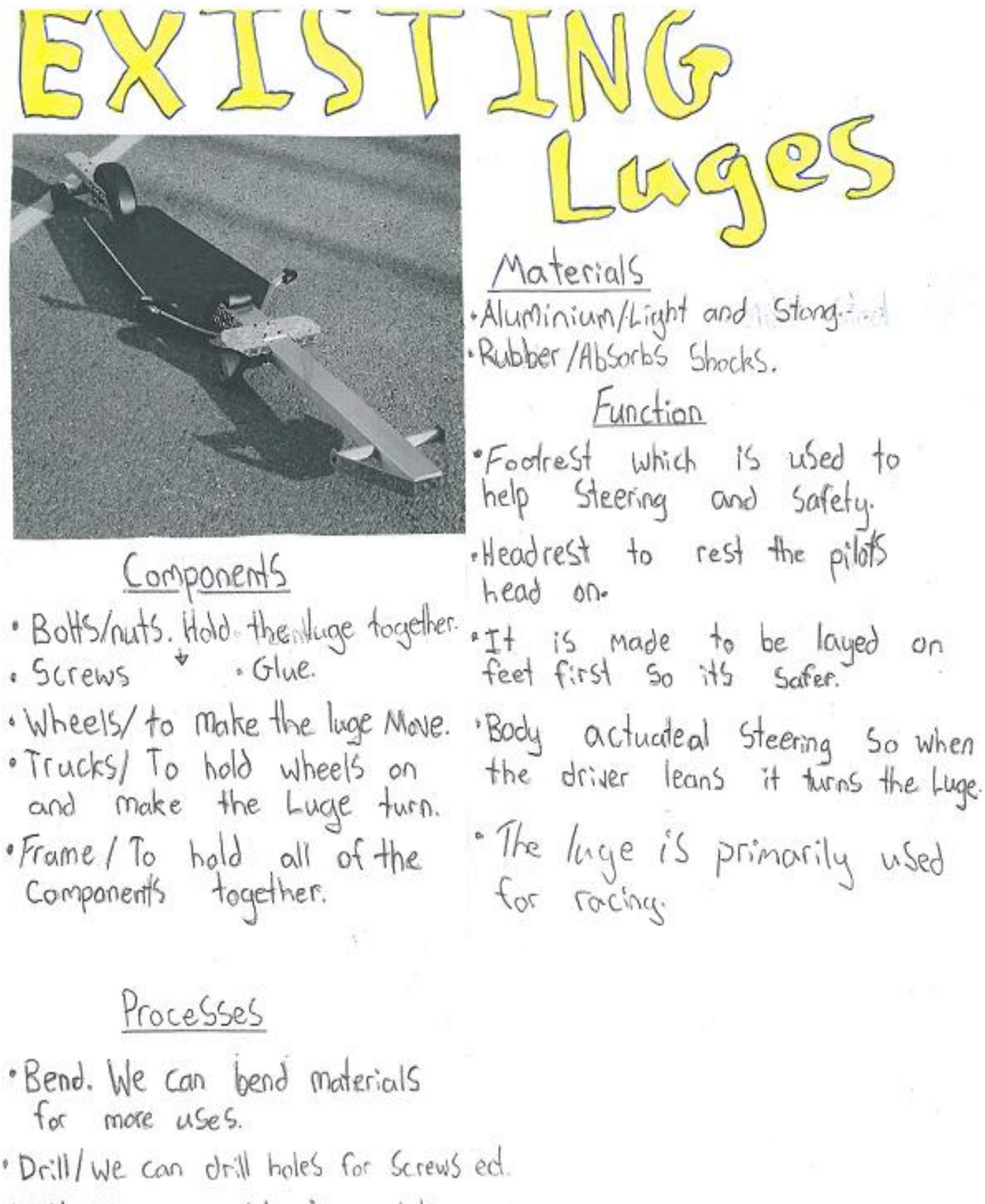


Figure 4.5 Luge research conclusion presented by a student in his technology portfolio.

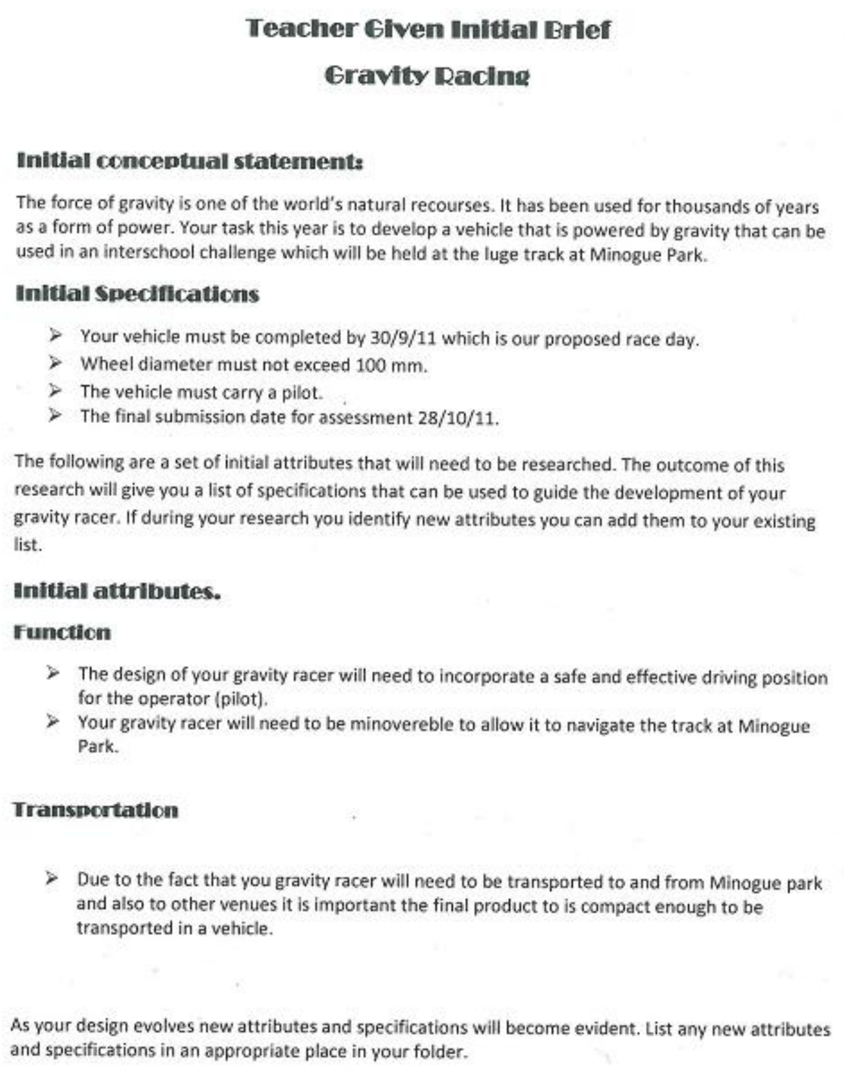
A page from the student portfolio shown in Figure 4.5 highlights the level of research conducted by the students to identify the functioning of luge, materials, components and processes involved in construction. Once a luge was selected to be further investigated, the various materials, components, processes involved in assembling them were studied. Students were advised to choose two different types of luges and to explore new designs and functioning of the components. Once the students searched a range of luges available on the internet, they were directed to draw their initial concepts. The teacher specified that before moving on to the next stage of designing, it is important to have developed a conceptual design which reflects their intended design. According to the teacher, this is a good stage for the students to put their ideas on paper before they find the constraints related to the materials and design.

4.3.3 Concept Drawings

The teacher instructed the students to refer back to their luge research as a reference in drawing their concept designs. Instructions were provided by the teacher about how to structure three dimensional drawings by introducing the concept of lines of symmetry and parallel lines. He started with drawing parallel lines and divided the plane to make body pans, frames, wheels, headrests, nose cones and a foot rest for the luge. The teacher made a 2-Dimensional picture of the luge and added 3-Dimensional effects on to the diagram. Students were instructed to draw two concept diagrams before they proceeded to draw the final concept diagram for their luge. The rationale for drawing two concept drawings before a final one was to give them an opportunity to put their ideas on a sheet of paper to select the most appropriate luge design and to check the feasibility of the design ideas. The final concept diagram was expected to be more realistic in terms of the materials to be used for their design. The teacher decided that the final concept drawing should be drawn after they had learned more about the materials and conducted some materials tests. In an informal discussion between the teacher and the researcher, he mentioned how students were getting some practice of drawing lines of symmetry, graphics, areas and proportions while drawing their concept diagrams. Even though it may not be the level of mathematics they did in their maths classrooms, the teacher noted that technology provides an opportunity for the application of some basic mathematics in the form of measurement and calculations. At this stage, students did not seem to be utilising any advanced mathematical concepts.

4.3.4 Initial Design Brief

The initial design brief hand-out was distributed to the students for the first time after they had completed their two concept diagrams. The design brief sheet defined the 'conceptual statement' for the project as 'to make a gravity powered vehicle'. Initial specifications in terms of completion dates, wheel diameters, pilots and final submission dates were provided. The teacher believed that the outcome of the specifications would guide the students towards the development of a luge. Initial attributes were identified to incorporate function in terms of safe and effective driving positions. Another attribute discussed in the design room was regarding the transportation of the luge to the place where the race day is set to take place.



Teacher Given Initial Brief

Gravity Racing

Initial conceptual statement:

The force of gravity is one of the world's natural recourses. It has been used for thousands of years as a form of power. Your task this year is to develop a vehicle that is powered by gravity that can be used in an interschool challenge which will be held at the luge track at Minogue Park.

Initial Specifications

- Your vehicle must be completed by 30/9/11 which is our proposed race day.
- Wheel diameter must not exceed 100 mm.
- The vehicle must carry a pilot.
- The final submission date for assessment 28/10/11.

The following are a set of initial attributes that will need to be researched. The outcome of this research will give you a list of specifications that can be used to guide the development of your gravity racer. If during your research you identify new attributes you can add them to your existing list.

Initial attributes.

Function

- The design of your gravity racer will need to incorporate a safe and effective driving position for the operator (pilot).
- Your gravity racer will need to be minovereble to allow it to navigate the track at Minogue Park.

Transportation

- Due to the fact that you gravity racer will need to be transported to and from Minogue park and also to other venues it is important the final product to is compact enough to be transported in a vehicle.

As your design evolves new attributes and specifications will become evident. List any new attributes and specifications in an appropriate place in your folder.

Figure 4.6 The initial design brief for the gravity powered luge.

Figure 4.6 shows the design brief which was provided to the students before luge construction. Specifications and attributes were discussed in detail by the teacher in the design room. Safe and effective driving positions were discussed with respect to the luge as an attribute the students would be required to fulfil as part of their assessments. The teacher thereafter directed the students to the workshop to discuss properties of materials for construction in reference to a constructed luge.

4.3.5 Studying a Constructed Product

References were made to the possible materials students may use for their luges and this was initiated by taking the students to the workshop. This gave students an opportunity to begin developing their final concept drawing and considering the best materials they could use to construct their luge. The students had already done some units on forming, combining and manipulating materials, and all this information was presented as a chart in the workshop. Two luges constructed in previous years were also displayed in the workshop, which again initiated curiosity and discussions among the students.

The structural integrity of the luge shown in Figure 4.7 was discussed, including the lamination and processing of the body pans, alignment of the frames along with the footrests and nose cone. The term 'tensile strength' was also defined and explained by the teacher during this stage as:

> The strength of the material before it deforms bends or breaks. So if we can select your materials and get really good tensile strength, in other words, they are not breaking, then we should test them and we can get the right materials for the right job. (Teacher, Classroom Observation Recording, Stage 1)

The teacher directed the students to have a look at both the luges which were displayed in the workshop to learn about the materials and components.

Figure 4.7 Luge displayed on the right hand side of the workshop.

The materials used for the components, and the processes to manipulate those materials were extensively discussed in the workshop. The teacher mentioned that the luge in Figure 4.7 has been designed to achieve a lower centre of gravity so it could provide a safer riding experience. The structural integrity of the luge was also discussed in terms of the construction of body pans as shown in the excerpt below.

T: But what has the student done to it to keep the strength in the plywood?

S 1: He has laminated it

T: But then what else has he done?

S 2: Made it curvy?

T: Yes he has bent it. So to form a bend in that plywood he has formed it with a press, so the tensile strength of the plywood is maintained.

Discussions about the structure of the frame and its fixing to the body pan were also carried out in the workshop around the constructed luge. Students were highly motivated to be in the workshop and to experiment with the available materials. It could be said that the students discussed the properties and strength of materials within the context of the luge. This phase helped the students to learn about the materials, manipulation techniques, various components and overall assemblage to form the luge, so developing contextualised knowledge which was being co-

constructed by the participants within the design context. This was also evident from the data collected from the student questionnaires.

During the Stage 1 interview with the teacher, he mentioned that studying already constructed products can provide students with information on the functioning of the luge components to assist them in making logical decisions about their own design, and the materials and processes to be incorporated in their product. Examining the functioning and assembly of the components provided the foundation to integrate cross-disciplinary knowledge. The technology teacher agreed that technology has proven to be an area which provides a good vehicle to promote other subjects and was willing to integrate information from science in his future sessions.

4.3.6 Concept of Neutral Axis

The idea of laminating plywood to create a curve was introduced to the students while studying the constructed luges. The teacher explained the idea of placing weights on top of two rectangles oriented on its two sides as seen in the diagram drawn by the teacher in Figure 4.8.

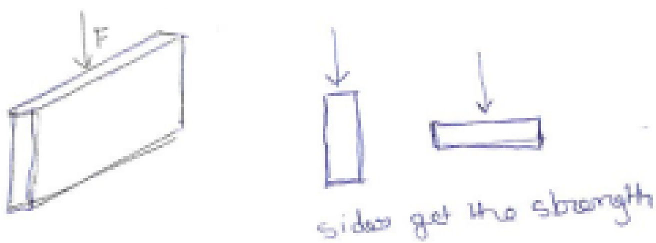


Figure 4.8 The diagram drawn by the teacher to discuss the strength of the sides of a rectangle.

Students were asked to identify the best position to apply a load which would provide the most resistance towards bending. A student identified that the side with the most material in the vertical plane will provide more strength. The theory behind bending was briefly explained to the students using scientific terminology like the 'neutral axis' and the variation of the radius of curvature when 'pressure' is applied at the top as shown in Figure 4.9. The term 'pressure' in this context was used by the teacher during discussions.

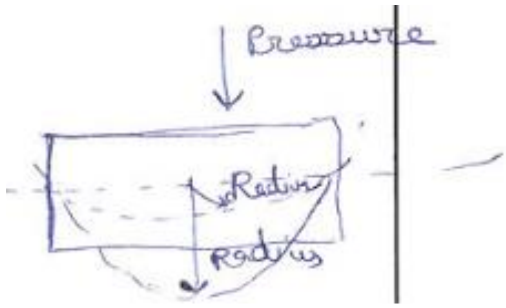


Figure 4.9 Diagram drawn by the teacher to explain the neutral axis and the radius of curvature.

The teacher introduced this concept as he identified the importance of selecting the appropriate material and applying load (weight) along the appropriate axis to prevent bending. The teacher noted during the sessions:

> When you start putting materials to start strengthening things you will understand what we are talking about. We will be looking for materials that are going to have the strength we need. (Teacher, Classroom Observation Recording, Stage 1)

The teacher instructed the students that they would be using different kinds and combinations of materials to make their luge. Discussion around the structure of the frame and its attachment to the body of the luge for stability was again carried out in the workshop. The physical properties of fibre glass, carbon fibre, Kevlar, plywood, steel and aluminium were discussed. The process of lamination of plywood was demonstrated to the students before the teacher asked them to do it by themselves in groups. Students already had prior knowledge of the concept of lamination as something which adds to the strength of materials. The teacher was preparing the students to observe the testing of plywood and mild steel under load conditions. The teacher mentioned to the researcher in an informal discussion:

> You know how in science you do experiments and we write them up. In technology, a lot of pupils are working on their own so they do their own stuff and they will write it up, this is really good learning. So they are not just putting it in together by themselves but also observing how it is done and can write down the conclusions for it. So you know it's a kind of new area of doing testing in groups. So we will test it and photograph it and write up the conclusions. So it's

> like teaching science in technology. (Teacher, Classroom Observation Recording, Stage 1)

The teacher considered manipulating and testing materials as a crucial aspect in technology. This provides a learning environment where students learn and perform experiments to provide evidence for decision making. At this stage, the researcher thought it will be useful to provide extra information regarding tension and compression in beams where loads are applied in the transverse direction. The next phase for the students was to perform some material testing experiment on plywood and mild steel.

4.3.7 Material Testing- Knowledge of Tension and Compression

The researcher discussed with the teacher the idea of integrating the information on tension and compression, and an agreement to introduce the information to the students was reached. The researcher developed a hand-out (in Appendix E) which the teacher identified as useful information for the students in context of the luge. This discussion took place while the laminated plywood from the previous sessions was being inspected by the teacher. Terms from science like 'compression', 'tension' and 'tensile strength' were frequently raised to connect it to the context of properties of materials and to create a shared meaning among the students. The teacher explained how materials like plywood can be manipulated to add extra strength using fibre glass. Four sets of test experiments were planned to be conducted using laminated plywood. The first test included the laminated plywood with no fibreglass, and consecutive tests included fibreglass in between, at top and bottom of the laminated plywood. Students observed the behaviour of the plywood with and without fibreglass to see whether it was worthwhile combining them together to make the material stronger. The application of tension and compression within the context of material testing was demonstrated to the students creating an environment where scientific concepts naturally aligned with the technological practices.

The initial discussion which began before testing demonstrates the students' understanding about the tensile strength of a material. The classroom discussion which took place is as follows:

> T: What is tensile strength?

Ss (a couple) - indicated a vague understanding of what tensile strength is but finally referred to it as the

- point where it breaks

T: Then how do we measure it?

S: By measuring the stretch.

T: Before it breaks or before it bends or deforms or whatever. Okay, so a material is designed to absorb a load applied to it, if it gets too much for the material then the material will bend or break and that is the tensile strength.

The students had some understanding of tensile strength which was demonstrated during the discussions using simple terms. They also understood that another rationale for the tests in the workshop was to efficiently use materials by making positive judgements during the construction phase, specifically if they would be requiring fibreglass to achieve the desired strength. The four tests were conducted in the workshop using a hydraulic press and the laminated samples. As shown in Figure 4.10, the samples were held between two supports and a load was applied from the top. The amount of stretch or dip before breaking was measured using a vertically placed ruler. The results from each test were recorded by the students and presented in their portfolios.

Figure 4.10 The testing of laminated plywood with a hydraulic press.

An explanation of the phenomenon observed was derived by discussions among the teacher and students in terms of tension and compression. The teacher was encouraging the students to explain the observed phenomenon using the available data and their knowledge of tension and compression. It was concluded that laminated plywood with fibreglass at the bottom provided more strength and improved the performance of the material under external loads. This phase provided students with an idea about the behaviour of plywood under the action of external weights. The explanation behind the observed phenomenon was also purposefully integrated during this phase to provide a practical understanding of the theory of bending.

Similar demonstrations were carried out on samples of square (25×25mm) and rectangular (25×50mm) steel tube. This test was carried out mainly to demonstrate the strength of steel and the possibilities of its use in the luge project. During the demonstrations, the theory on tension and compression was reintroduced to the students. Previous knowledge about the neutral axis and the layer at the top and bottom being compressed and stretched were recalled in the workshop while testing. The teacher elaborated on the relationship between the length of the side and the tensile strength of the steel rods (square and rectangular beams). Students seemed to enjoy this session as they mentioned during informal conversations with the researcher that it was practical and hands-on.

4.3.8 Integration of Knowledge about Tension and Compression

The 'tension and compression' hand-out prepared by the researcher was distributed to the students in the design room. The teacher explained the rationale for providing the hand-out to the students. The application of force to the beams was again discussed and explained in the classroom with respect to the context of the luge. The concept of the neutral axis, and tension and compression was recalled and elaborated in the design room.

The knowledge of tension and compression was applied to the context of the luge while the teacher explained the rationale for adding the fibreglass to the bottom of the laminated plywood as follows:

> We tested it, and it snapped at a certain point, so we know that was going to measure the maximum depth that we can push our plywood

> down before it broke. (Teacher, Classroom Observation Recording, Stage1)

The compression and tension force was discussed in detail by the teacher throughout the session. Instructions on how to apply those principles were then presented before going through the hand-outs. The teacher encouraged the students to apply the thinking and explanations provided in the hand-outs to draw the conclusions for the material testing phase. Students were provided with information on the strength of plywood and steel so they could make informed decisions about materials for their luges using the information from the hand-outs to support their choices.

An informal conversation was conducted with the teacher after this session to collect his perceptions regarding introducing the concepts of tension and compression to the students. He seemed a bit frustrated as the students got disoriented towards the end of the session. His frustration was evident as he commented:

> I am sick of this now as I think I had enough of this, now they need to make decisions by themselves, they need to start recording it and you can tell when they are not interested because they kind of go off with it, they will go away today, but when they come in I will get started with them again, but the thing about this is that they need to show me in their selection of materials and design that they have applied these principles to it, that's what I will be looking for. Even though they are in year 11 they still need to know how to do it. (Teacher, Classroom Observation Recording, Stage1)

The teacher mentioned that there was a lack of interest in the classroom towards the end of the theoretical session, which the researcher also noted. This may be attributed to the amount of theory taught to the students which caused them to become distracted during the sessions. The teacher recognised the importance of the content from science and mathematics in luge design and again referred to the purposeful integration with frustration during the Term 1 interview:

> It was frustrating at the time because you think you are getting that information through to them and a day later you come back and it is

> not there and then you give them as many examples and show them as many times in the workshop but, sometimes it is just not there. Now it is not there, either they don't understand or it's not there because they don't want to understand, and I don't know which one of them it is … but not all of them. (Teacher, Classroom Observation Recording, Stage1)

Students mentioned that the information from the tension and compression hand-outs was helpful (Appendix E). It provided them information for which they could see a practical application and so attach meaning to the context. This helped the students to choose the right combination of materials for their luge. This indicates that explanations of the investigations and experiments can provide authenticity to the context if carried out in an integrative fashion.

The teacher indicated that the use of materials plays a significant role in technology and has potential to integrate scientific knowledge through its manipulation and through an understanding of its properties. The teacher felt that the problem provides a motivation to conduct research testing and selection of materials. Once the information on materials and instructions on the processes is gained, it then provides a better understanding of the parameters and constraints of the design. The testing of materials involves considerable science and mathematics, as discussed in the previous paragraphs. This indicates that to integrate science and mathematics in a technological design context requires some level of expertise in understanding materials and an explanation of their behaviour using scientific and mathematical principles.

Student opinions were also collected about when the information on tension and compression should have been integrated. The summary of the data is presented in Table 4.1 which was recorded from the student questionnaires (end of Term 2).

Table 4.1 Statistical data on when the information on tension and compression should have been integrated from Student Questionnaire

	Time for integration of tension and compression information		
Student Total	Before Testing (Materials)	During Testing (Materials)	After Testing (Materials)
19	7	10	2

Many students responded that such information should be provided to them while physically doing the testing because they can observe and learn the phenomena at the same time. Students mentioned that it provided an idea about the strength of materials and the reason behind their observations. Some said such information should be provided before they go and do the testing so they have a prior understanding of what to expect, and then they will better understand what is happening during the testing. A few students indicated that they would prefer to know the information after the testing phase so they could know what happened during the testing. The data from the student questionnaires indicates the reason students lost concentration and became disoriented towards the end of the theoretical session was the strong focus on science. This indicates that providing a strong focus on teaching science in technology should be carefully carried out and with a purpose.

Students were constantly encouraged to write up their conclusions of the material testing along with the rationale for choosing a particular material for their luge. This helped the students to have a better understanding of the materials before they started their final concept drawings. The conclusions derived by the students indicate a high level of thinking and incorporation of scientific principles from the hand-outs to justify their conclusions. Thus the discussions and significance provided at the material testing phase was recognised both by the teacher and his students and were successful in explaining their observation using science. The conclusion derived by one student after the testing of materials is shown in Figure 4.11 (a) and (b).

Plywood:

In the workshop we tested four differently laminated pieces of plywood with most including fibreglass mating and resin that was applied to the wood. This testing of plywood was to find which would work the best by having the most tensile strength to incorporate into our products whilst being light and efficient for building our luges in the workshop. We tested 2 pieces laminated together on their own. Secondly we tested 2 pieces laminated together with fibreglass in the middle of the plywood. Then 2 pieces laminated together with fibreglass stuck on top. And finally 2 pieces laminated together with fibreglass on the bottom. It was evident that the 2 pieces of plywood laminated together with fibreglass on the bottom was the strongest and was the most resistant to deforming under pressure being applied to the top of it. The reason for this from research has been that the fibreglass mating has increased the strength of the wood on the bottom. This is where tensile strength is needed because the wood in this place is under tension where's the wood on top does not need as much strength because it is under compression and will not break at that point. Therefore the 2 pieces laminated together with fibreglass on the bottom will be best for building my luge.

(a)

Mild steel:

In the work shop we tested two different sizes of steel square section. One was 25mm x 25mm. And the other was 25mm x 50mm.
Pressure was applied to the top of the steel to test the tensile strength of the metal until it deformed. The 25x25 square section took ¼ of a ton to deform where's the 25x50 steel square section took ½ ton to deform. As we found out the 25x50 took double the pressure to deform. The reason for this is because we have doubled the wall high of the steel meaning there is twice as much pressure needed to deform the steel. This is because we have also two times as much material on either side of the neutral zone meaning that twice as much tension (pull) and compression (push) is in the steel to strengthen the metal. This has been made evident that the 25x50mm steel square section is the strongest. Although it is the strongest it will be around about twice as heavy. Therefore the 25x25mm steel square section should be best for building my luge as it is still very strong as I am highly unlikely to be applying over ½ a ton on my luge and it will be lighter as I will be using less material to build and construct my project.

(b)

Figure 4.11 The students' conclusions from the (a) plywood and (b) mild steel testing and selection.

The student has clearly described the procedures involved in testing with a sound explanation of the observed phenomenon in scientific terms. The practice of integrating information from science during investigations enabled the student to make technological decisions based upon his observation. Evidence of logical decision-making processes can be found in student portfolios regarding material testing and selection. This may imply that providing explanations with predictions in technology can add on to the learning experience of the students. The teacher could have completed the material testing phase without providing any detailed explanations behind the observations, but it was appreciated by the students and incorporated while justifying their design decisions.

4.3.9 Physical and Chemical Properties of Materials

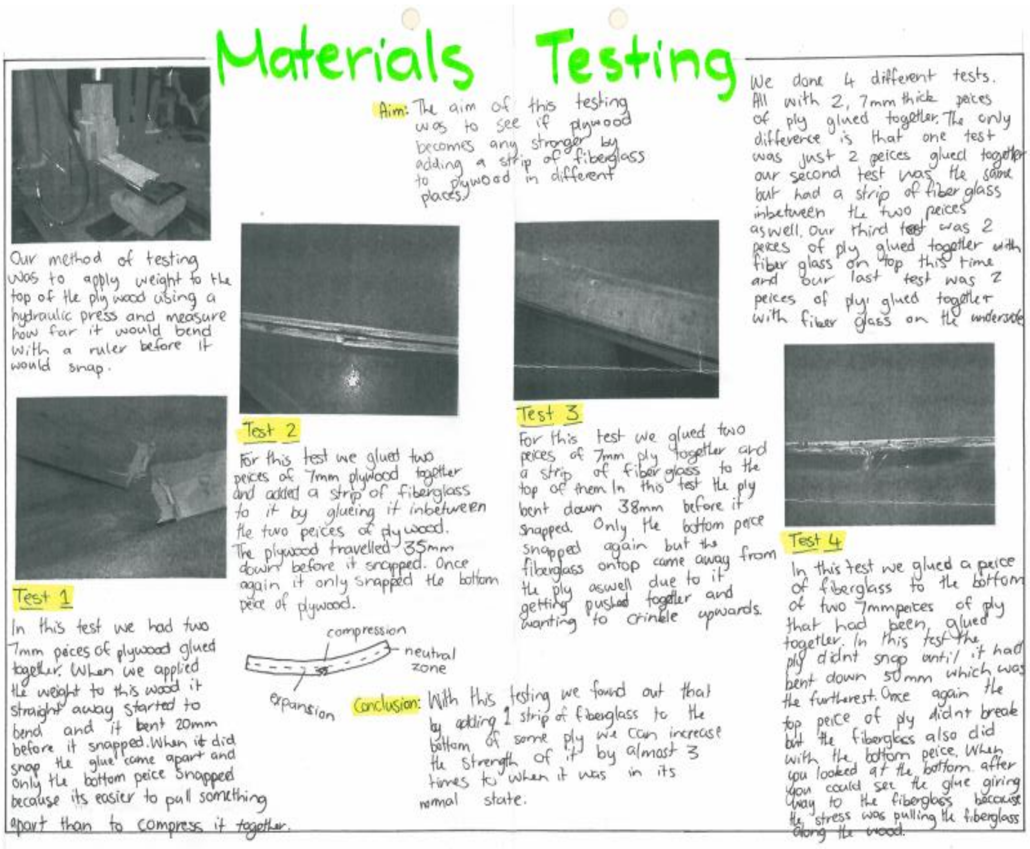
The teacher encouraged the students to consider the environmental impact and other wear factors to be considered before selecting the materials for the luge. Students understood that the luges will be used outside on a street, so it was essential to consider the environmental impact on materials. Therefore, the various protection techniques for timber and mild steel were discussed. Prior knowledge on treating these materials was recalled by the teacher and students from the previous year. The teacher noted in the workshop:

> Last year we did the scooters, mild steel we know we can bend it, we knew it was strong, it could be painted because we know it's going to rust, we could weld it, drill it, cut it and turn it on the lathe. You guys know all that stuff, and now you need to make sure that you go back and think about that [process knowledge] and recall it. (Teacher, Classroom Observation Recording, Stage1)

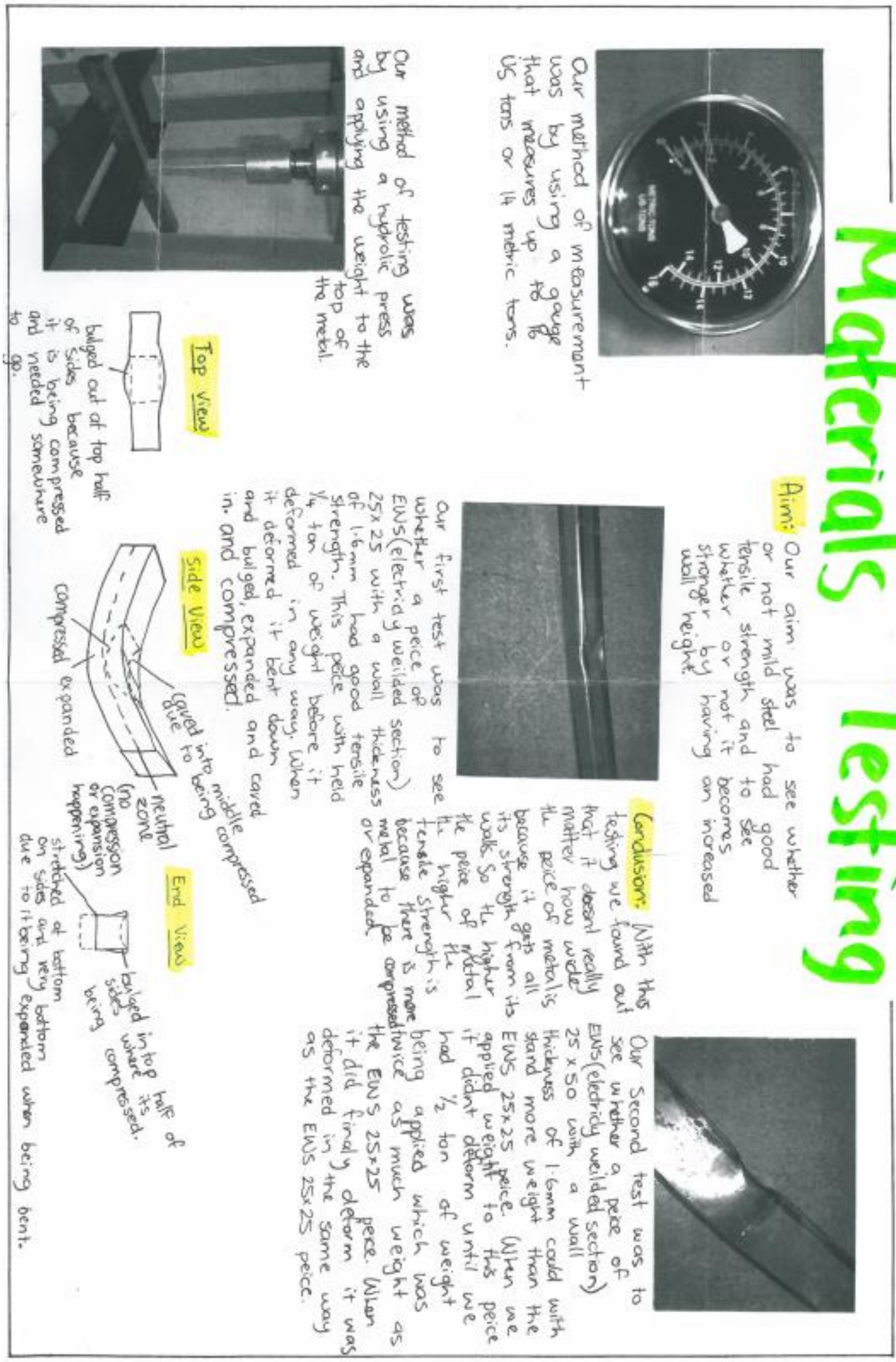
In the teacher interview conducted towards the end of Term 1, he highlighted the importance of prior knowledge in technology. According to the teacher, prior knowledge about materials, its properties and manipulative techniques are considered to be significant before constructing the product. Lack of prior knowledge of materials and processes has to be identified beforehand so the teacher can make provisions to accommodate them in his lesson plans. According to the teacher, such knowledge provides confidence and understanding to start looking at a problem in-depth. The teacher next instructed the students to work on the presentation of their conclusions from the material testing which will be discussed in the next sub-section.

4.3.10 Conclusions derived from Material Testing

The conclusions drawn by the students in the portfolios indicate a sound understanding of the procedures involved in testing plywood and steel and the explanation of the behaviour in scientific terms using mathematical calculations. Student portfolios show evidence of the incorporation of the concept of tension and compression in their explanations and rationale for material selection. Portfolios also incorporated the ideas from the diagrams in the tension-compression hand-out as evident in Figure 4.12. Students also used their own language to explain their observations which aligned with the science principles. These conclusions were informed by the information discussed by the teacher during demonstrations using scientific terminology. An example of a conclusion from materials testing derived by a student is shown in Figure 4.12.



(a)



(b)

Figure 4.12 (a) Test results from laminated plywood with and without fibre glasses, (b) Test results from rectangular and steel rods compressed under the hydraulic press.

There was evidence in the student portfolios regarding the application of knowledge from tension and compression for explanations of the effect of load on laminated plywood and steel tube. Learning about the materials and functions of the luge enabled the students to explore a range of variables. The teacher noted that:

> They started coming to me after that with questions like, If we drop two weights, which one will hit the ground first? Their science thinking was coming in but they were thinking in relation to a project so introducing things like the momentum, weight, materials testing, the knowledge of materials so all those things initiate them bringing in skills from other areas. (Teacher, Classroom Observation Recording, Stage1)

The teacher also realised the information to integrate science and mathematics sometimes happens naturally in technology, indicating the knowledge co-constructed in technology is contextualised which could be extended further to accommodate science and mathematics. The teacher also indicated that there were many instances where students asked questions where he had to recall knowledge from other subjects. The teacher noted in the interview conducted at the end of Term 1:

> Just about everything, for example in the materials knowledge, about the tensile strength, about the maths, about if we turn the materials on its side we are going to increase the strength by four times, the momentum, just the weighing and measuring of students, comparison of weights, heights, getting averages and all that sort of thing is happening but we are probably not realising that we are doing it. (Teacher, Interview, Term 1)

Information about the properties and manipulation of materials in technology has a component of applied science. Knowledge regarding the physical and chemical properties of materials is applied to help derive the required outcome in technology. Technology starts with a brief or problem and while trying to fulfil those needs, knowledge from other domains integrates naturally. Technologically advanced procedures exist and have rationales for their existence. It is while getting to know why certain procedures exist and are considered technologically advanced integration of knowledge could be initiated. Decisions then need to be made whether detailed explanations including scientific or mathematical knowledge are required or whether to rely on predictions and tacit knowledge in technology to develop the product.

The teacher mentioned that, as an outcome of integration, students developed their problem-solving abilities. Students took initiatives to start talking about their science and mathematics knowledge without realising what they were recalling basic information from science and mathematics.

4.3.11 Final Concept Drawing

Students gathered information during the momentum testing, luge research and material testing phases which provided an opportunity for them to think about their final concept drawings. The teacher expected the students to refer to all these sources of information and to incorporate their revised ideas in their final concept drawings. The concept of aerodynamics was also introduced in the classroom by the teacher. This provided an opportunity for discussion where students actively took part in incorporating science ideas as shown in the following excerpt from the classroom:

T: Aerodynamics, is that an attribute? What is aerodynamics? What is it all about?

S1: How the air circulates around.

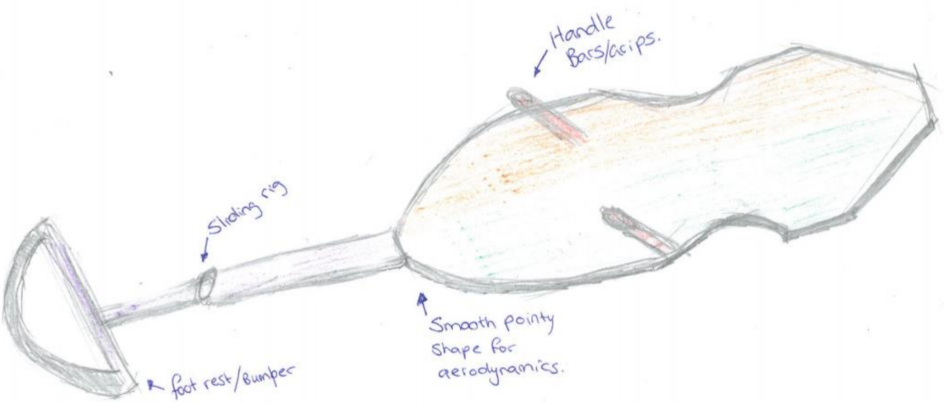
T: Okay! So what do you think you have to do to achieve that? So you are going to try and achieve some shape? Okay! An attribute could be that and the specification would be what?

S2: Laying down position for the pilot…

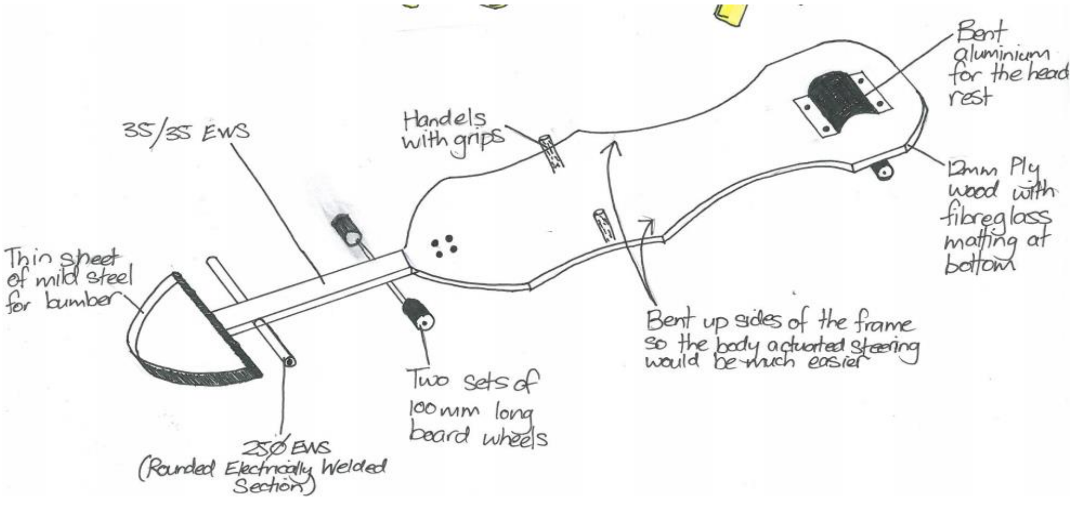
T: Will that give you aerodynamics?

S3: The front shape has to be pointed.

This indicates that students were connecting science ideas to the design of the luge when this was initiated or encouraged by the teacher. Students were being provided with an understanding of the various components which could be incorporated into their design. The assembly of these components with each other to form the overall luge gave students an idea about the positioning of the pilot and the shape they are trying to achieve for better steering. The teacher expected the students to reflect this understanding of aerodynamics in their final concept drawing. Students were also encouraged to think in terms of the shape of the body pans and frames, and the placement of the wheels to provide effective weight distribution of the pilot in their final concept drawings. Three examples of the final concept drawings have been included in Figure 4.13 from the student portfolios to illustrate the level of thinking incorporated by the students in terms of materials, components and their assembly to form a luge.



(a)



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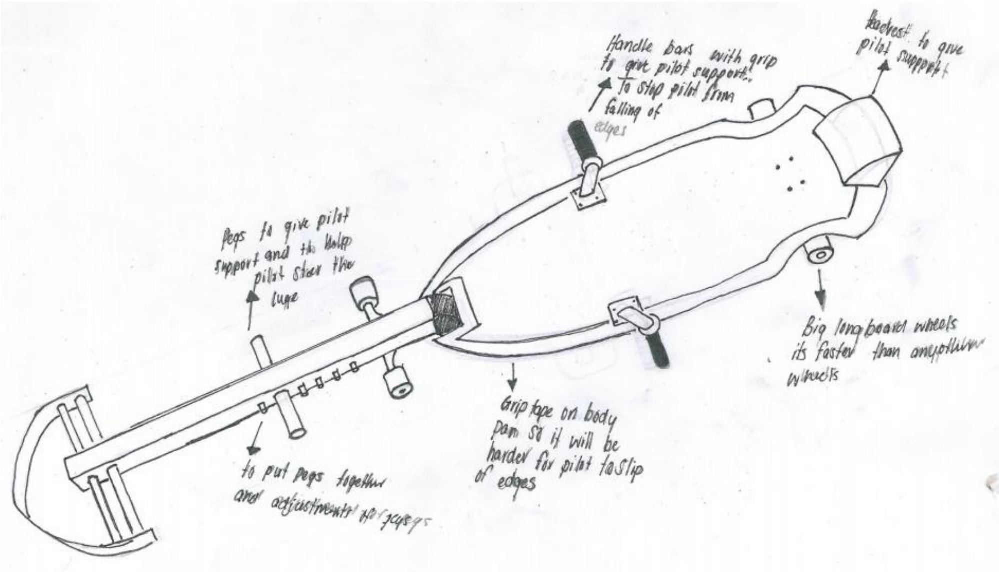


(c)

Figure 4.13 The final concept drawings from student portfolios presenting the shape, materials, components and their functions.

The student portfolios indicate the level of understanding students gained regarding the shape of the luge, materials for the components, positioning of the wheels, functioning of the components and their positions. One student indicated that he would be using fibreglass at the bottom of his plywood for the body pan as seen in Figure 4.13 (b) which indicates how the student was successful in recalling knowledge (information about tension and compression) gathered during the material testing phase while drawing. This indicates that the student understood the incorporation of fibreglass at the bottom of the pans would support the weight of the pilot. The concept of aerodynamics was also referred to with respect to the shape of the luge as seen in Figure 4.13 (a), which indicates the application of scientific notions of aerodynamics. This may indicate, to some extent, that students apply science during appropriate selection of materials with or without realising. The next phase of the project included making a cardboard pattern for all the components of the luge.

4.3.12 Cardboard Pattern

The making of the cardboard pattern involved the students taking their own anthropometric measurements (height, shoulder width, weight) and their stakeholders measurements. Stakeholders were people external to the project (parents, guardians, brother, sister, friends) who will also be riding the luge. The students had to make the luge custom fit for themselves and their stakeholders. Any stakeholders involved in their project were also expected to be considered at this stage and their measurements were also recorded. The maximum and minimum lengths of the individuals (including stakeholders) were taken by students.

The teacher then provided instructions on how to proceed with making the card-board patterns. The body pan was to be cut from a 1200mm x 400mm cardboard sheet. This sheet could then be used to incorporate the individual specification and shapes of the body pan, frames, headrest, footrest and nose cones. Students were expected to make a template of the body pans by gluing two pieces of cardboard of 600mm x 400mm together to make it 1200mm long. For this purpose, the teacher took the dimensions from the constructed luge. This accommodated the dimensions of the constructed luge in the workshop. The teacher advised the students to work on the body pan first before the frames.

The teacher's rationale for developing the cardboard patterns was that making a full size pattern will allow students to lie on it, mark out the positioning for their headrest, footrest and nosecones and finally, towards the end of Term 3, to check whether the constructed luges would fit in their vehicles for transportation purposes. Basic mathematical measurements were involved during this phase because the cardboard pattern had to be custom fitted to the body as seen in Figure 17 and Figure 18. The use of low level mathematics during such procedures is more realistic than non-contextual calculations as the product has to be customised according to the requirements of the users.

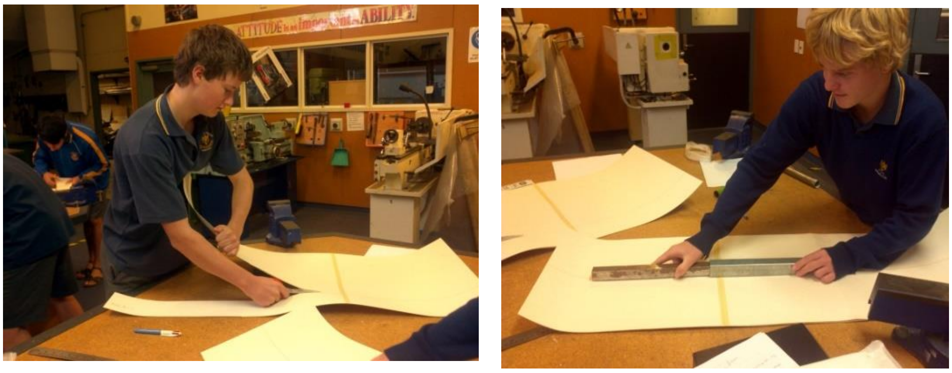


Figure 4.14 Photographs from the workshop indicating the measurements students performed which included checking for symmetry, parallel lines and incorporating sizes of the stakeholders

The luge on display in the workshop provided a good reference point for teacher-student discussions. The teacher wanted the students to think about their own body and the area of contact they may require when piloting the luge. He referred back to the luge hanging in the workshop for the students to observe the shape of the body pan. The teacher initiated a discussion around the luge:

> It is kind of cut out so that the shoulders get maximum contact at the top and also down further where the pan is it has got maximum contact with your backside and whoever made that one has cut down the sides a little bit, I guess for the shape of it to give it a nice form. (Teacher, Classroom Observation Recording, Stage1)

It was observed that the constructed luges present in the workshop would influence and govern the design decisions made by the students in terms of manipulation and processing techniques. The understanding of the materials and their manipulated form was provided to the students by making continuous reference to the workshop luge so it would influence their design decisions. For example, the structural integrity of the luge was discussed in terms of the arrangement of the body pan with the frames as evident from the teacher's comments:

> One piece of plywood is usually very wobbly but by making it like a curve adds strength to it. Also, with the chassis underneath it will add to the strength of the material. (Teacher, Classroom Observation Recording, Stage1)

The arrangement of the various components was carefully studied by the students (assisted by the teacher) to understand the structural integrity of the luge. The teacher encouraged the students to interact with the materials and to gather information on the width of the pans and chassis along with the forces that would be acting on them. Student knowledge from the previous phases was recalled during the cardboard design pattern making stage. A conversation with the teacher towards the end of the session revealed that he wanted the students to make decisions for selecting the best materials to obtain the required strength. This was encouraged by giving the students an opportunity to create a prototype pattern to check dimensions. Informal conversations with the students indicated that they enjoyed the kind of work which involves sketching and freehand drawings as it was more practical than other academic school subjects. They mentioned (some with a surprise) that they do a lot of basic mathematics like measurements which involves minor calculations in getting the maximum length of the body pan and the frame, and taking into account the stakeholder requirements.

The cardboard pattern also provided an opportunity for the students to think in terms of the assembly of the various components which would be a part of the luge. The researcher had a conversation with BA during the cardboard pattern phase, after which BA made some changes to his final concept diagrams. BA thought about the structure of his luge during this phase which involved making the chassis smaller to save material and to lighten his luge. This indicates the thinking a student can put into the design stages to make his luge structurally durable. Students were laying down on their cardboard patterns to work out the best riding position (see Figure 4.15). The teacher instructed the students to lay down on the patterns to mark the position of the hand grips and head rests.

Figure 4.15 Students collaborating and helping to mark handgrip and headrest positions.

It can be seen from Figure 4.15 that considerable collaboration occurred during cardboard pattern making. This process involved problem solving by the students, as they were expected to position themselves to mark the position of the footrests, handgrips and the nose cones which was not physically possible by a student working alone. The positioning of the steel or wooden frames was also drawn on the cardboard pattern which properly aligned with the body pan. This indicates that the students were thinking in terms of placement of the weight on the luge and its structural stability, or else they would not have made the frame drawings beneath their body pan designs.

Instructions were provided by the teacher to draw top and side views for the luge using the cardboard pattern to calculate the arrangement of the chassis with the body pans. The cardboard pattern in Figure 4.16 indicates the measurements and design decisions involved in deciding the position of the body pan, frame, footrest, headrest and nose cones. Students may have thought about the approximate positioning of their weight on the body pan and worked out the arrangement of the frames beneath the pan to support the weight. It can be seen in Figure 4.16 that the student thought about the positioning of the frame (steel rod in this case) to support the body pan. The material for the frame was also decided at this stage.

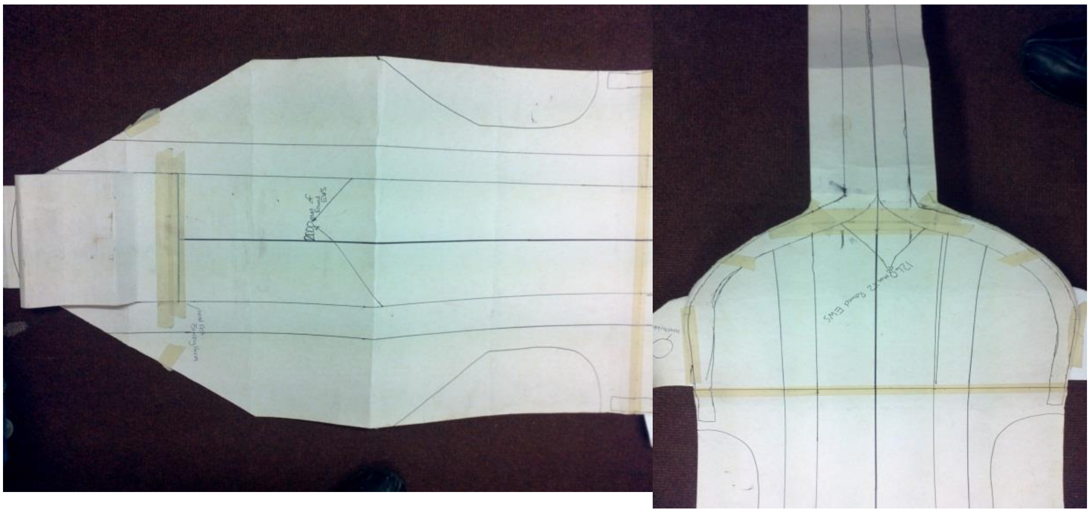
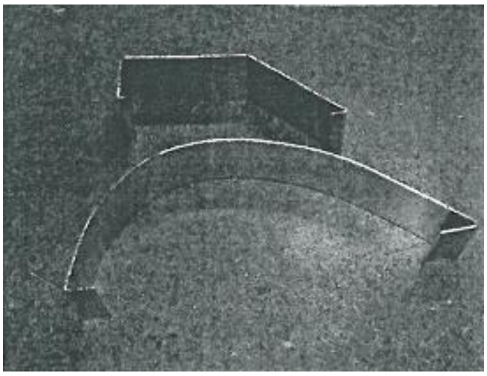


Figure 4.16 Card-board pattern of a student indicating the position of the frames supporting the body pan.

The students also used basic calculations and drew lines of symmetry in these cardboard patterns. These cardboard patterns exhibit the thinking involved in drawing the correct positioning (as deemed by the student) of the steel rods which has a potential of initiating a trial and error process for the later stages of construction.

4.3.13 Process Testing

The teacher wanted the students to be familiar with processes like welding, gluing and cutting before they started making their luges. To accomplish this task, he divided the class into groups and assigned them to carry out different processes like bending, laminating and welding so they could decide whether they would utilise the process in making their luge. The rationale for dividing students into small groups was to provide enough time for students to observe and perform various processes to take appropriate design decisions. Since the focus of the teacher and students was to develop a functional luge, manipulative techniques were important. Advantages of the processes were discussed in the workshop after students became competent in undertaking the procedures by themselves. The students were already aware of the materials suitable for their luges at this stage, so the skill development provided them an opportunity to reaffirm their selections and to choose the manipulative techniques most suitable for the material. Previous knowledge was recalled from mathematics in these sessions with regards to welding pieces of steel at an angle. The teacher took photographs of the processes and distributed them to the students to include in their portfolio conclusions. Students were expected to decide, explain, and justify their use of each process. Some photographic evidence taken from the student portfolios of the procedures carried out are shown in Figure 4.17.



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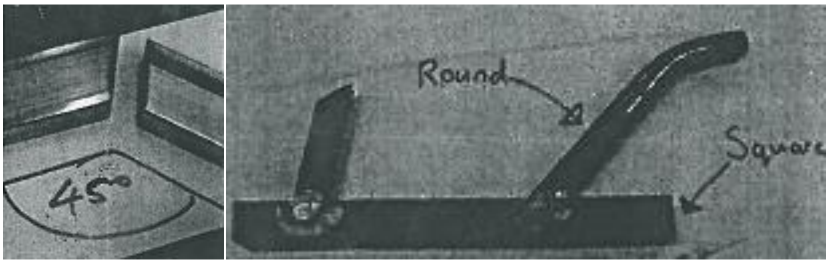

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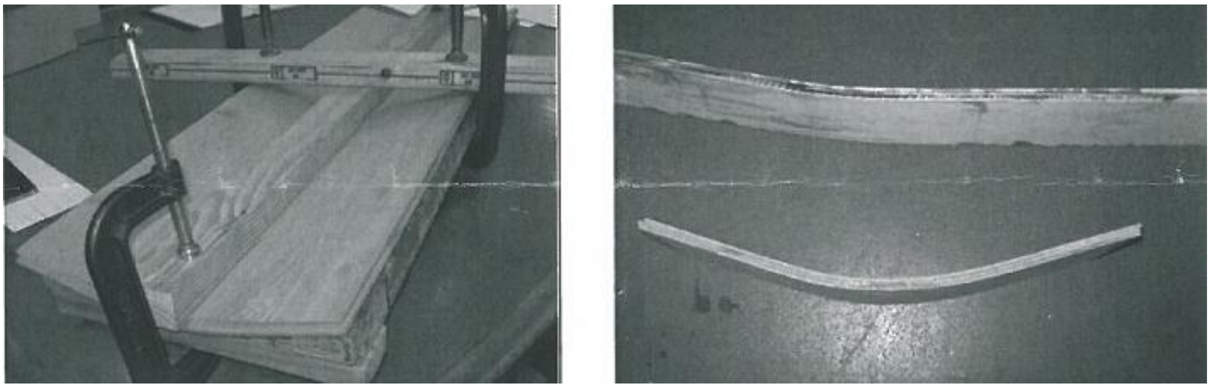


(c)

Figure 4.17 Processes carried out by the students in the workshop: (a) bending of aluminium, (b) welding of steel sections and (c) laminating and bending plywood.

Examples are presented from student portfolios which demonstrate a clear understanding of the rationale for process testing (material manipulative techniques) and conclusions drawn by the students. Students have identified the usefulness of the process in relation to their luge design and identified safety issues. Students learned about manipulation techniques and properties of these materials as shown in Figure 4.18.

We then took a piece of aluminium sheet and marked it out. After we had marked it out we then had to bend it I the school bender, and achieved the head rests shape. After we had bended it we then had to see if we could make the same shape with the roller. So we also marked another piece and rolled it in the school roller and rolled it until we had the same shape as the bent one. After we had done that we then linished the aluminium to see if it could be made to look tidy. So we put the aluminium on a drill with a special drill head to achieve this.

Individual summary (suitability for your project)

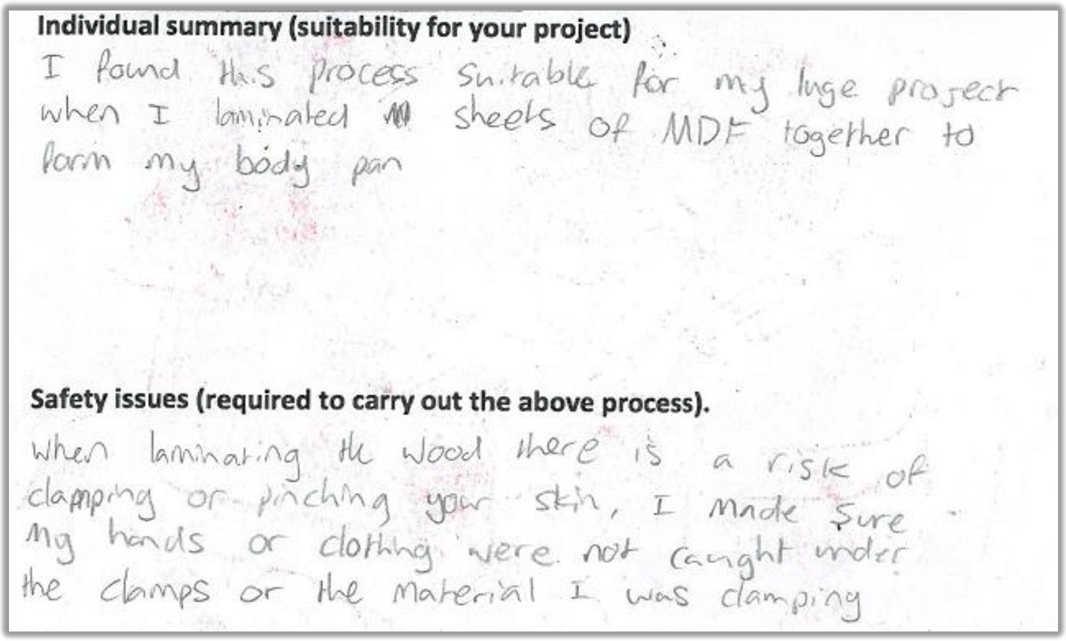
This is not suitable for my head rest because I am going to use shaped laminated plywood which is covered in foam and then vinyl for looks and confort. (The vinyl needed to be stapled into wood)

Safety issues (required to carry out the above prosess).

Saftey glasses when using the linishing machine, and only one person at a time using machinery.

What was done?

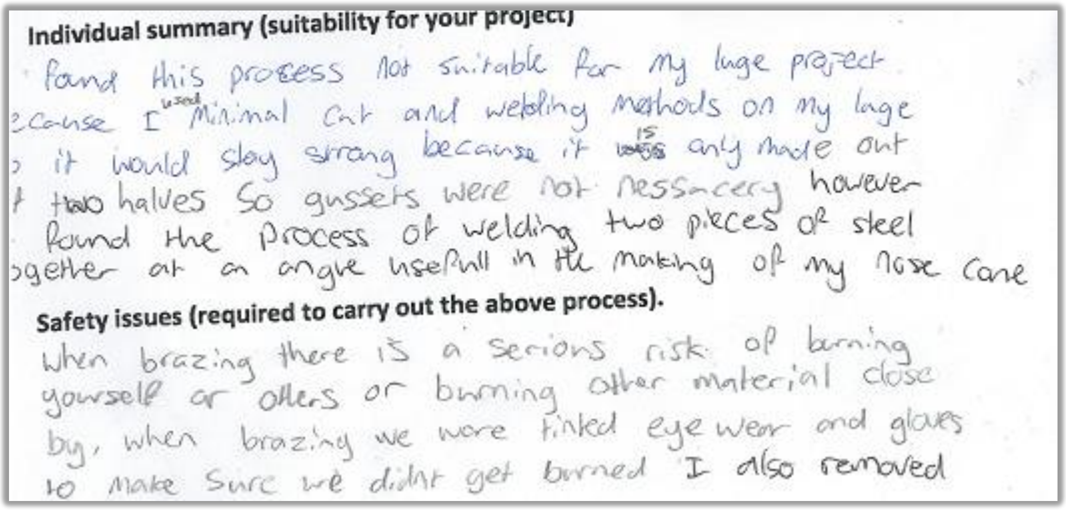
The process testing which was carried out which included, Laminating and bending of sheets of plywood. The first process that was carried out was laminating 2 pieces of 4 mm plywood together using P.V.A glue, with the addition of fibreglass mating which was glued on the bottom to reinforce the tensile strength of the plywood. We manipulated the wood by using the flat surface of the bench, then by placing a wooden block under the plywood which required clamps to hold the wood together and to enable us to form the bend we wanted.


Individual summary (suitability for your project)

I found this process suitable for my luge project when I laminated sheets of MDF together to form my body pan

Safety issues (required to carry out the above process).

When laminating the wood there is a risk of clamping or pinching your skin, I made sure my hands or clothing were not caught under the clamps or the material I was clamping


Individual summary (suitability for your project)

found this process not suitable for my luge project ecause I used minimal cut and welding methods on my luge it would stay strong because it is only made out f two halves so gussets were not nessencery however found the process of welding two pieces of steel ogether at an angle usefull in the making of my nose cone

Safety issues (required to carry out the above process).

When brazing there is a serious risk of burning yourself or others or burning other material close by, when brazing we wore tinted eye wear and gloves to make sure we didnt get burned I also removed

Figure 4.18 The process testing along with the summary and safety issues identified by two students.

The information from science could also be seen in a few portfolios where the students tried to justify their selection of the process based upon their selection of the material and the scientific rationale. For example, DR's portfolio (see Figure 4.19) indicates that he decided to use the lamination process of bending plywood to design curved shapes for his body pan and frame. The student indicated that his rationale for choosing the technique was the suitability of the material for his intended purpose and explained briefly how the shape of the manipulated material would help him achieve higher speed (lower centre of gravity). TG's portfolio indicated that he preferred the lamination method for constructing the right bend for his frame as 'my luge would be lower to the ground'. TG also mentioned that selecting the process of welding (to improve welded joints) for his steel frame would also be beneficial as his luge would ‘drop down’ to bring the centre of gravity lower to the ground (see Figure 4.20). This indicates the thinking students may have done in terms of selecting their material and process which naturally enabled them to think in terms of science which is contextualised and embedded within the context.

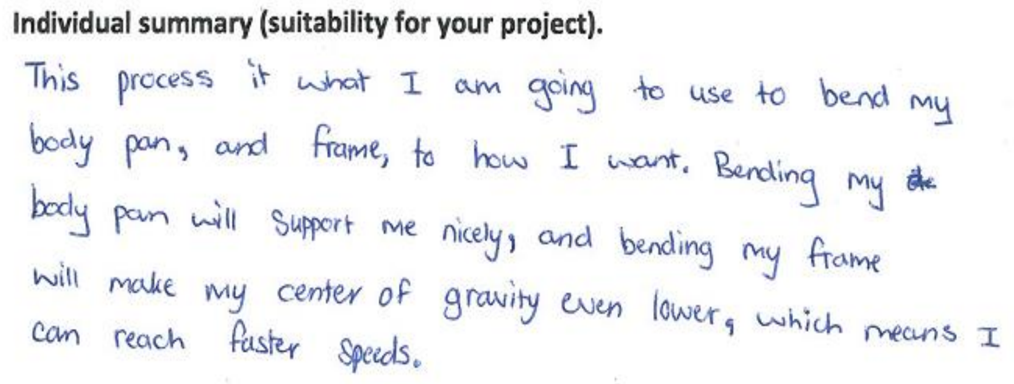


Figure 4.19 DR’s individual summary and suitability for the project.

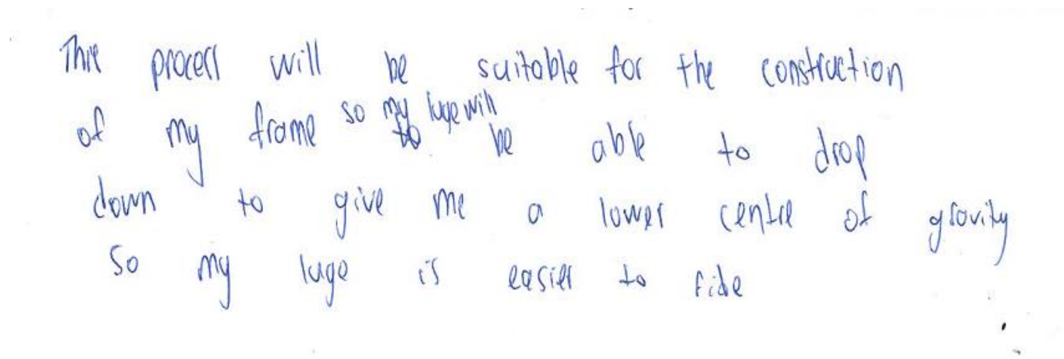


Figure 4.20 TG’s individual summary and suitability for the project.

The students included the reasons, procedures, photographic evidence, and safety issues associated with the process. The advantage of the various processes was studied by practically performing the procedure and identifying the safety factors for the individual processes. This design environment provided motivation and interest to the students as they acknowledged the importance of the hands-on experience in their learning (Student Questionnaires).

Students mentioned that interaction with materials provided them an opportunity to refine their ideas. The tensile strength of the materials was explained and practically demonstrated to the students, which helped them learn the flexibility of the materials both through material testing and process testing. Learning about the nature and performance of the material was also identified by the teacher as an aspect crucial in technology. Students learned about various processes involved in forming, manipulating and testing the materials which helped them to construct a luge fit for its intended purposes.

The next section presents the summary from the final questionnaire introduced towards the end of Term 1.

4.4 Perceptions of Knowledge involved in Stage 1

The questionnaire introduced towards the end of Stage 1 (Term 1) was intended to record the perceptions of the students regarding knowledge involved in luge designing. Even at this early stage, the application of knowledge from other subjects was considered to be a crucial aspect towards the completion of the luge by the students. Students made references to knowledge from various subject domains in their responses. They understood the importance of the practical aspect of technology while incorporating knowledge from other domains, especially from science and mathematics, to complete their design.

The data collected from the student questionnaire administered towards the end of Term 1 provided further evidence of the science and mathematics concepts/calculations students had utilised while designing their luge. The students referred to concepts from science and mathematics without being prompted to do so, indicating that concepts can naturally integrate within a technological design context. The question and the responses are presented in Appendix B.

It was observed from the questionnaire data that all the students except one identified science and mathematics as subject areas which they have used while designing the luges. Measurements and calculations were the common form of mathematics utilised by the students as indicated in the questionnaires. Concepts from speed and time, angles and trigonometry were also identified by two students. Science knowledge related to gravity, momentum, weight, forces, weight distribution, motion, environmental impact, physical properties of materials and aerodynamics were identified by the students as knowledge applied during designing. It can be said that all students, except one, identified science and mathematics utilised during the design stages.

The teacher advocated the extensive use of knowledge from other domains during Stage 1. Making the students think and inquire about the principles and concepts and their application in the context of the luge was essential since this provided an opportunity to bring together the ideas from other domains, like science and mathematics, to demonstrate their relevance in a technological design context. The teacher also identified that the next stage (construction) may deal more with measuring safety and handling.

4.5 Summary of Chapter

This concludes the Term 1 classroom observation for Stage 1. The initial term was dedicated to understanding the product in terms of its functions, materials, techniques for construction, properties of materials, concept drawings, customised patterns and consolidating the design ideas to prepare the students for the construction phase. The study also observed the potential in technology to naturally integrate science during investigations and while deriving conclusions. The terminology introduced by the teacher during discussions was rich in terms of both technological and scientific knowledge. Such interactions provided opportunities for the students to observe the application of scientific knowledge and led to the adoption of the scientific terms in their conclusions.

The next chapter examines the narrative of data from Term 2 and Term 3, collectively referred to as Stage 2, where students began constructing the various components of their luges.

CHAPTER 5- STAGE 2 OF CONSTRUCTION

5.0 Introduction

This chapter presents the data from the making stage, collectively referred to as Stage 3 (Term 2 & Term 3). The data were generated using the researcher's field observation notes, informal conversations, researcher's self-reflection notes, student portfolios, digital images and Term 2 questionnaires. A narrative account of the instances which led to the construction and completion of the luge is presented for this stage. The teacher's role was slowly being shifted from teacher to facilitator during this stage, as the responsibility for learning was shifted more towards the students.

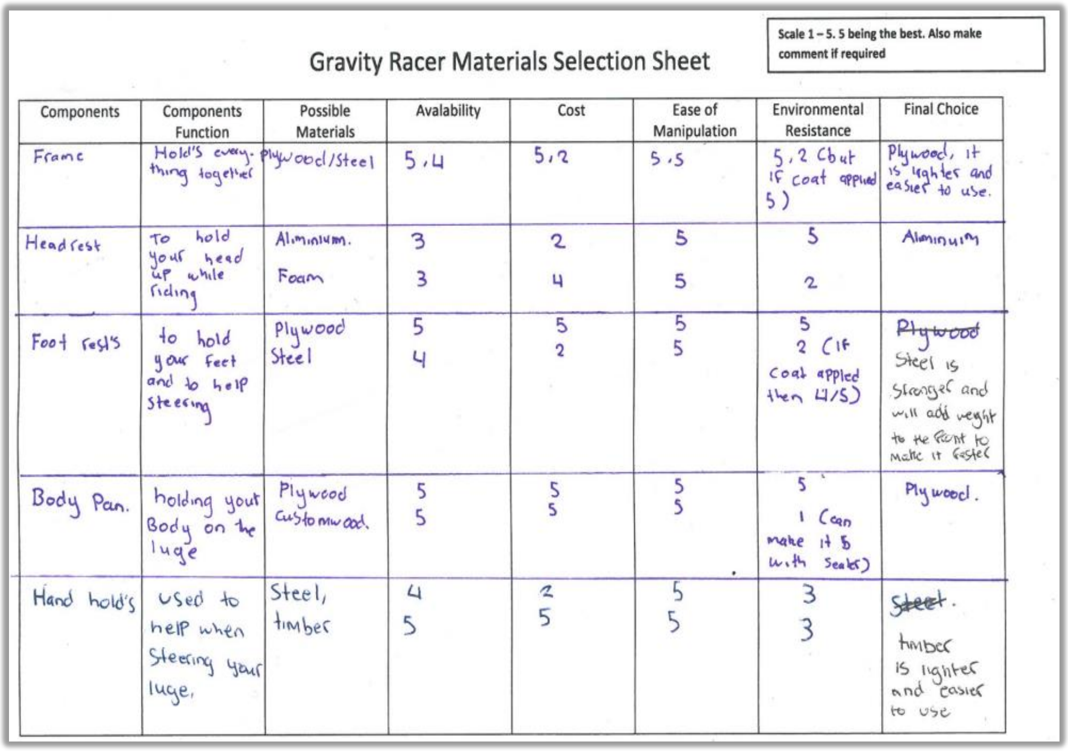
The data from the classroom observations and field notes will be presented in a chronological sequence of events until the end of Term 3 (September 2013). The free nature of student movement in the workshop facilitated researcher access and conversation. The teacher took the students to the design room to provide any relevant information to the whole class. The workshop was an environment where students made their individual luges with enough working space around them. The high noise levels in the workshop due to the operations of machinery and tools prevented the researcher from audio recording the conversations.

5.1 Stage 2- Making the Luge

At the beginning of the term, the teacher distributed a 'Gravity racer material's selection sheet' to be filled in by the students to decide on and justify the type of materials they would be using for the luges before starting construction. The teacher provided instructions on the presentation of the material selection data sheet. He started to discuss the assembly of the chassis of the luge and provided information on its function as holding the body pan and frame together to support the pilot's weight.

Continuous references throughout Stage 2 were made to the luge research phase completed by the students in Stage 1. The data sheet required students to make a judgment on the availability, costs, ease of manipulation and environmental impact of materials. The information on materials, manipulation and processes was recalled by the teacher to help students think through the type of materials they had planned to use for their luge. The concept of environmental resistance and its effect was briefly discussed in terms of the materials they might use during construction. The properties of steel and plywood were recalled and the processes of making them environmentally resistant were discussed. The cost and availability of plywood and steel were also briefly discussed, indicating a domain of knowledge distinct and context specific to technology.

There were classroom discussions among the teacher and students regarding possible materials for their luges and their ease of manipulation techniques in the workshop. The teacher encouraged students to widen their choices about possible materials and to justify their selection in their portfolios. The functions of the luge components were again identified during the sessions before the students started to fill in the material selection sheet (see Figure 5.1). Students were instructed to discuss in groups to complete the material selection sheet to finalise the materials before they started construction of the luge.



Gravity Racer Materials Selection Sheet

Scale 1 – 5. 5 being the best. Also make comment if required

Components	Components Function	Possible Materials	Avalability	Cost	Ease of Manipulation	Environmental Resistance	Final Choice
Frame	Hold's every-thing together	Plywood/Steel	5, 4	5, 2	5, 5	5, 2 (but if coat applied 5)	Plywood, it is lighter and easier to use.
Headrest	To hold your head up while riding	Aluminum. Foam	3 3	2 4	5 5	5 2	Aluminuim
Foot rest's	to hold your feet and to help steering	Plywood Steel	5 4	5 2	5 5	5 2 (if coat appled then 4/5)	~~Plywood~~ Steel is stronger and will add weight to the front to make it faster
Body Pan.	holding your Body on the luge	Plywood Customwood.	5 5	5 5	5 5	5 1 (can make it 5 with Sealer)	Plywood.
Hand hold's	used to help when steering your luge,	Steel, timber	4 5	2 5	5 5	3 3	~~Steel~~. timber is lighter and easier to use

Figure 5.1 The material selection sheet filled in by a student.

Once the students had completed the materials selection data sheet, they were allowed in the workshop to start the construction of the body pans. The completion of the material selection sheet took nearly three classes by the students in the design room, which indicates the time provided by the teacher to think and make design decisions about materials. The next section will discuss the construction of the body pan.

5.1.1 Body Pan Construction

Students were taken to the workshop to demonstrate the process of lamination to make the body pans curved. The teacher provided them with some background information of what is to be expected as an outcome of the lamination process. The teacher instructed the students as follows:

> The process is that we glue them together and clamp them down and we leave it to set for 24 hours, and when you come back in tomorrow you can take off your clamps and it will retain the shape you want. So the process is that you glue the stuff up and when you have done that you take them out the next time and mark out your shape on your timber and then cut it out using bench saws, work from a line of symmetry up the middle because we did that on your cardboard pattern so make sure your measurements are right. (Teacher, Classroom Observation Recording, Stage 2)

This lamination procedural knowledge was introduced together with some components of applied mathematics like calculations and lines of symmetry, in the context of the luge. The manipulative technique was discussed purely in terms of tacit and descriptive knowledge of processing plywood to achieve the required strength. This provided an opportunity for discussions in the workshop based on the rationale for using thin pieces of plywood over thicker pieces for construction purposes. The advantage of using thinner pieces over thicker pieces of plywood to create a curved shape was briefly discussed in terms of stress distribution, which was recalled from Stage 1 discussions. The information on tension and compression was recalled by the teacher in the context of the plywood as indicated below.

> Thicker materials when they bend they have a lot of tension and compression and it is not easy to get a three-dimensional shape for that material. (Teacher, Classroom Observation Recording, Stage 2)

The researcher observed that the teacher lacked competence in providing the right scientific explanation behind curved laminated plywood providing extra strength to the shape. The content knowledge from science possessed by a technology teacher can affect the extent of integration in a technology classroom by introducing the content during proper stages of construction. The teacher made it explicit that the manipulative properties and techniques of plywood would be a major part of their external assessment for NCEA, so they had to understand the properties and draw conclusions from the material testing phase.

The process of lamination was carefully demonstrated by the teacher as pictured in Figure 5.2. This involved many measurements and calculations and consideration of the lines of symmetry on the plywood sheets to determine the position of the wooden block at the centre to get the right amount of curve for the body pan.

Figure 5.2 The lamination process of plywood demonstrated by the teacher to the students in the workshop.

The laminated plywood was left clamped overnight for the glue to set and retain the curved shape. The plywood successfully retained its shape the next day when the clamps were taken off. Students seemed to be excited to see the new shape of the plywood. The students were instructed to proceed with the lamination of the plywood and to clamp it in for 24 hours to form a curved shape.

The teacher allowed the students to complete the process of lamination before he proceeded any further with the construction of the body pan. He instructed the students to refer back to their cardboard pattern to trace the shape of the body pans onto the curved plywood (see Figure 5.3). This phase also enabled the students to think in terms of the effective use of the materials for the body pans. Students made reference to the cardboard pattern to determine the most effective shape of the body pan with minimum weight. The teacher and students understood that the weight of the luge needs to be less for the luge to be aerodynamic and to sustain a controlled steering mechanism. The body pan was cut to specific shapes chosen by the students (in concept drawings) and this took weight off the body pan to make it lighter.

If a need for new information on scientific, mathematical or procedural knowledge was as identified by the teacher, he would simply call the students in the workshop to assemble at a workbench. Here is an instance where the teacher explained DC's work to the whole class around his workbench:

> DC has put his line of symmetry at the middle. He has lined it up with his line of symmetry on that one and drawn his pattern on the plywood. Now the next thing I ask you to do is to take some measurements at different points just to make sure that it is of the same shape and size. (Teacher, Classroom Observation Recording, Stage 2)

Figure 5.3 Student tracing the shape of the cardboard pattern onto the laminated plywood.

Information regarding processing of the plywood to achieve the desired shape for the body pan was also provided to the students in the workshop by demonstration. Students were competent with the use of both bench saws and jigsaws to cut the plywood because of previous technology classes. Students were also helping each other at times to saw the body pans. The teacher also introduced, through demonstration, a step-by-step procedure for cutting plywood which the students then applied to their project as shown in Figure 5.4. As anticipated by the teacher in the Stage 1 interview, discussions between teacher and students on technological practice were prominent early in this workshop stage. From the researcher's perspective, the focus of the teacher and the students was on making the body pan durable and strong.

Figure 5.4 Student working on sawing the body pan to achieve better finishing.

The teacher took the role of a facilitator during this phase of the project, helping students as and when required. Students lay down on their body pans to check for comfort and to determine the approximate position of the hand grips. There was considerable critical and collaborative thinking evident among students during the making of the body pans, for example, helping to draw the shapes of the cardboard pattern on the plywood, providing and sharing ideas on cutting and sawing the plywood. This exchange of ideas and thoughts indicated social participation and the co-construction of knowledge specific to the context.

There were instances in the workshop where the teacher helped the students change their body pan design based upon the properties of the material they were using. The teacher helped EM to decide upon the design and structural integrity of the body pan as his material was custom wood. This demonstrates the significance of the correct choice of materials in technology to fulfil the intended purposes. The properties of custom wood were discussed with the students again around EM's workbench:

> I have just been talking to [EM] about this, and I have got two concerns; one is that it is really thin across here now, and we know custom wood is not that strong, don't we? So if he takes all that out [pieces of custom wood] from his project, then there is a good chance that it is going to break in the middle. Even if it is sitting on the frame and when he pushes on it, there is a chance that it could break, so you need to try to leave a fair amount of material in the middle otherwise it will break, don't worry about plywood. (Teacher, Classroom Observation Recording, Stage 2)

The teacher also helped EM to change the design of his body pan. EM agreed that the new design was better than the original, and changes would be made accordingly while constructing the body pan. The teacher played a role as a facilitator and expert who can provide timely advice on materials and help the students develop critical ways of thinking.

The conversations the researcher had with the students enabled them to explore the rationale behind the curved shape of the body pan. This would have provided an indication of whether the student had logically thought through their actions. The data from this informal conversation is presented in Table 5.1.

Table 5.1: Student rationales for the curved sectional shape of the body pan

Student	Rationale
KM	Looks cool and got the idea from the luges in the workshop
TG	Looks better I guess and don't know
NT	It is easier to turn, if it is straight it is harder to turn
SS	I don't know, it can be straight as well but may not help with the steering
BA	Looks better
EM	Looks better and adds strength
JC	It helps in body actuated steering and adds strength to it
MY	Lower to the ground and provides more aerodynamics and helps with steering
JP	Gives more area of contact to the shoulders and easy to steer
MQ	Looks good and is stronger because of double plywood

ST	In order to have a good stability of the pilot along with the ease of turning it is necessary that the shape of the body pans need to be like a 'concave'
LG	It looks better to have a curved and angled body pan. It is also comfortable to the rider, saves material and provides a controlled navigation to the rider
HM	It helps in navigation and turning of the luge

Source: Researcher's informal conversations with students.

These rationales indicate that there is some understanding by the students about why the shape of body pan was to be curved. Students answered in terms of factors like aesthetics, steering, material property of plywood and aerodynamics. MY commented that the body pan needs to be curved as it lowers the centre of gravity and air drag. The curved shape of the body pan lowers the frame-pan (chassis) assembly to the ground and provides controlled navigation, but MY's claim that it also provides less drag does not seem consistent. The students indicated some understanding of the rationale for their actions, and the shape of the body pan. A Few students had difficulty identifying the function of the body pan in terms of its structural significance.

The researcher conversations with the students indicated their perceptions around the issues they faced while making the pans (Appendix B). These classroom observations and informal conversations show that the students found the experience of shaping the body pans, such as sanding and sawing along with doing the mathematical measurements to make the product customised, tedious. The process of tracing the cardboard pattern on to the plywood involved making sure the pattern was drawn symmetrically with appropriate measurements. Individual designs also included special curves and rounded sections on the body pans and the students reported during the conversations that the experience of producing a finished body pan was tedious and tiresome because of the various problems they faced during practical development of the body pan.

In an informal conversation with the teacher, the researcher shared the student's thoughts about the issues they faced while making their body pans. The teacher mentioned his concern about the inability of the students to recall processing knowledge with steel and plywood from the previous year when they had constructed scooters. A new technological context different from the scooters might be a reason for their inability to recall previous knowledge and skills. The teacher also commented that some measurements may have gone wrong while tracing the patterns onto the plywood because they may not have measured and drawn the lines of symmetry properly in the first place. The line of symmetry had to be drawn on the plywood so it could be aligned with the cardboard pattern for a more accurate trace. This indicates that a technology teacher must not expect that the students will easily recall previous processing knowledge and transfer knowledge in a different context. The application of mathematics seemed to be problematic for the students since it was oriented towards designing and making a customised component of a luge which requires precise calculations and cognizance of design decisions which can influence the product.

There were numerous instances in the workshop where the teacher shared information on processing techniques of steel and plywood with a group of students. For example, JV received assistance from the teacher to use a chisel to make the sides of his body pan smooth. NT was present when the teacher was helping JV, so he quickly took the information and applied it to his own body pan. The procedural knowledge of manipulating the body pans was appropriated (through practice and participation) by students as they were spending more time on their body pans, and timely support was provided by the teacher. An informal conversation with NT indicated that the student learned the procedures of manipulation by observing other students or by depending upon the expertise of the teacher. NT also provided a clear rationale for varnishing the body pan (to protect the plywood from the environment), which indicates that the student could attach theoritical meaning to his actions.

Students' ability to learn the necessary procedural knowledge was of major significance as their final goal was to develop a working product. During these sessions, the researcher noted that it was important in a technology classroom to gain competence in the procedural knowledge of technology. The procedural knowledge is unique to technology and is context oriented. A lack of the necessary procedural knowledge makes it practically impossible to design and make in a design context. To implement a STEM integrated environment in a technology classroom, it is essential for the students to understand the procedural knowledge in technology. Because students come with an aim of designing, recalling information from science and mathematics will not be an immediate priority. The knowledge from the teacher is also a crucial aspect as he/she must be competent in the processes, material and cross-disciplinary knowledge to integrate as the need arises.

5.1.2 Planning the Construction

There were instances in the design room where the teacher would spend time helping students to plan towards the completion of the luge so there would be enough time for testing before the final race day. He distributed a time management chart for the students to plan for their completion; they had to think about the materials, processes and the resources they needed to complete their project within the set time. The teacher mentioned that the luge should not only be done for the sake of construction but also to win on the race day. He helped the students to logically plan the successful completion of each stage within the project and the resources needed for the completion of the luge.

The completion planning was done in the design room. The teacher wanted the students to finish the planning section as soon as possible so they could carry on with the construction. The next section will discuss the frame construction.

5.1.3 Frame Construction

The construction of the frames which provide support to the body pan is an integral part of the construction process. The alignment of the body pan to a wooden frame is shown in Figure 5.5. This phase involved considerable planning, problem-solving and calculations to be performed around the alignment of the frames with the pans to provide the required strength to the assembly. For example, when LG completed his body pan and started to work on the frames, he started to design his chassis which involved measurements, calculations and problem solving. LG was referring continuously to his cardboard pattern to determine the positioning of the bent circular steel rods (frames) beneath his body pan as shown in Figure 5.6. Frequent measurements were performed during this process to determine the amount of U-bend required for the rods to align with the body pans.

Figure 5.5 Positioning of the body pan on a wooden frame (lowered to the ground).

It was anticipated that LG's chassis would be made up of two circular rods supporting the body pan, as shown in Figure 5.6. Bending of the circular rods was carried out by the teacher and the student by setting up the appropriate bending apparatus in the workshop. The teacher helped LG to carry out the bending procedure, so that the other students also understood how the procedure was to be carried out while they were observing. The points where the bend was to be incorporated were marked and bent accordingly by the teacher.

Figure 5.6 Checking symmetry and alignment with the cardboard patterns.

A number of measurements were made in this process in regard to the length of handgrips (using measuring tape) and marking the points on the bending apparatus. The circular rods were then set on the cardboard pattern to check whether they were aligned properly to the frame (see Figure 5.7).

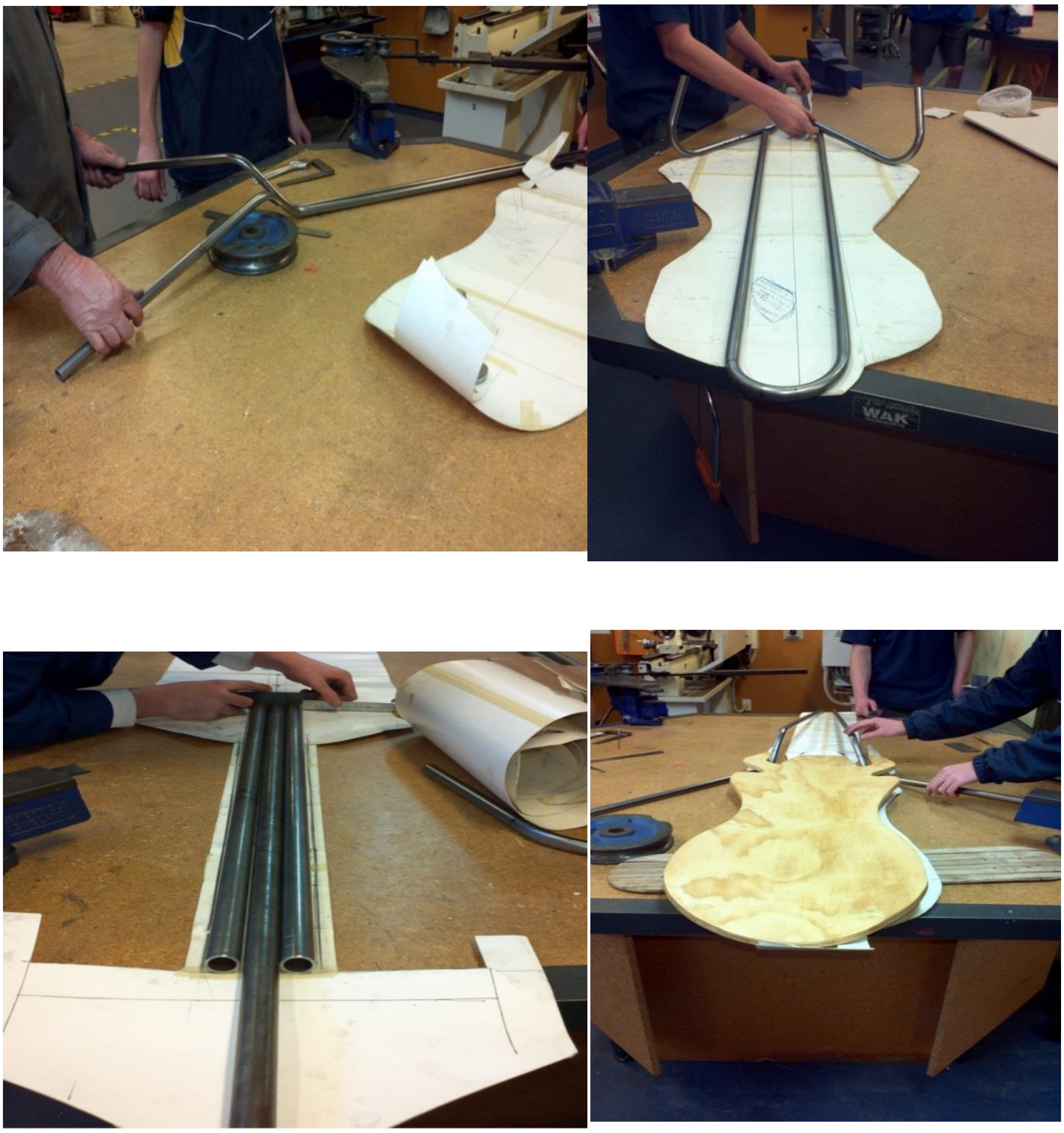


Figure 5.7 Bending rods and their alignment with the cardboard pattern.

Students who were present around LG's workbench quickly applied the same procedure to their own frames. They carried out the bending process and, as expected by the researcher, it involved many measurements and much thinking based on the amount of bend, and its alignment to the body pan (see Figure 5.8). LG had trouble getting the right amount of bend for his frames, so he sought help from the teacher. He seemed to lack the confidence necessary to do it by himself at this stage. Interestingly, LG had to make a change in his frame design during this phase. This indicates that the design ideas change while the students interact with materials as they become familiar with the context and start to identify variables affecting the luge. While constructing his frame, LG realised that his initial design would have failed as it was not capable of providing enough support to the body pan. So he changed his old idea and developed a new design which added extra strength to his luge (see Figure 5.8). The steel rods have now been placed and assembled in such a fashion that they provide extra support for the weight of the pilot.

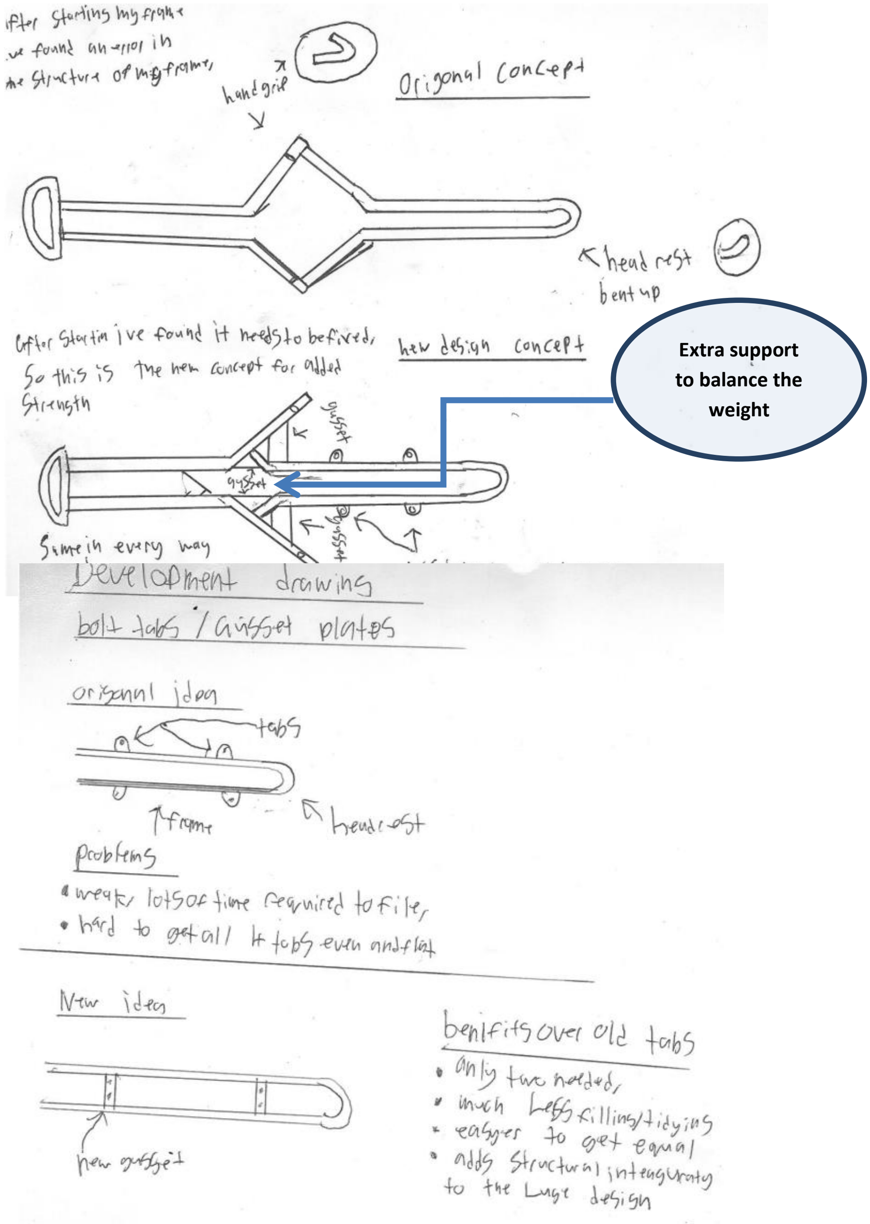


Figure 5.8 LG's design for his new chassis and frame with a comparison between the original and the revised design.

The new design clearly illustrates the problem solving abilities of LG as they emerged due to the interaction of the student with the design environment. LG (novice) and the teacher (expert) collaboratively realised the lack of strength in the original frame design when they aligned it with the cardboard pattern. The teacher commented on the problem-solving abilities and encouraged students to make changes to the original design if required:

> [LG] has got a tube frame and he has also drawn a frame which fits underneath his wooden pan. So he knew what it was like in his concept drawing and it has been easy for him to draw what his frame is going to be like. So [LG] has been able to bend his steel bits in the bender to the shape and then you might have to draw a side view to see how the frame goes up and down. (Teacher, Classroom Observation Recording, Stage 2)

Students made continuous references to the cardboard patterns during the alignment of their body pans and frames. They took their own body measurements and those of the stakeholders to determine the length of the chassis and frame. This helped them to decide the positioning of the frames with respect to the body pans so as to provide the maximum strength and support. The teacher then instructed students to think about the side views for their frames and chassis to determine the amount of dip/bend required to accommodate the body pans (see Figure 5.10. The teacher gave these instructions:

> You are ready to make your frame and now you got [sic] to look from the top. I can turn this sideways and kind of work out where the bends are going to go. Draw a centre line through the middle of your project and show the bend up here and put a line across the other side. How far we are going to bend it up? Well, you should have worked that out in your measurements so you can now say this is going to be lower, from here it is going to go up till [the body pan] and it is going to go along so now we are looking at the sides. Remember, we did it with the scooter and it is still out there on the noticeboard. (Teacher, Classroom Observation Recording, Stage 2)

The teacher believed that the cardboard patterns would help students to visualise in 3-D and decide upon the required elevation for their frames. This information was again recalled from the previous year's technology sessions which involved construction of the scooters.

Technology talk in terms of communication of material manipulation techniques and processes were prominent in the workshops among the teacher and students regarding the structure and positioning of the frame on the body pans. It was essential for the students to decide on the alignment of the pan with the frames and, most importantly, the side views for their luge. So these discussions with the teacher gave rise to a situation where students had to consider measurements and calculations to accommodate their body pans on the frames. Students were also observing the constructed luges which were displayed on the walls in the workshop which had its influence on students' design decisions.

The teacher also provided timely assistance and opinions on materials and their effective use. For example, DC was trying to make his frame by cutting and welding the steel rods. This process, as judged by the teacher, was time consuming, so instead, he suggested to DC an idea of bending the rod as LG did for his frame to accomplish similar results with minimum waste of time during this material stage.

During this period some of the students started to work on constructing their wooden frames in the workshop. For example, MQ had decided to use the wooden frame for his luge, and laminated his frame using three long pieces of plywood as shown in Figure 5.9.

Figure 5.9 MQ's Laminated plywood for a wooden frame.

MQ laid his cardboard pattern on the side of the laminated plywood to identify the points where the body pan had to be accommodated. This provided an idea to the student on how the dip has to be incorporated to accommodate the body pan on the frame altogether. The teacher wanted to discuss MQ's progress in the workshop with other students so he asked everyone to assemble near the workbench and said:

> MQ has now laminated up his frame and he has got his body ready and drilled some holes to get his luge together. So he is going to go in there today and put his body pan on the frames. Now, because he had made his plates, he just needs to drill holes in it and bolt his wheels and by the end of the week his luge is mobile. The good thing about the wooden frame is that you can slightly adjust it if you need to make it fit with your wooden body pan. (Teacher, Classroom Observation Recording, Stage 2)

The researcher had a conversation with MQ about how he could proceed to construct his wooden frame. He mentioned that he first lay down on his cardboard pattern and measured his body length to determine the position of his head and feet. The bend was decided by referring back to his body pan and working out the elevation required to fit his pan on the wooden frame. Then he proceeded by laminating three sheets of plywood together using his process knowledge from year 10 by gluing and clamping it to the workbench (see Figure 5.10).

Figure 5.10 Laminated sheets of plywood to make the wooden frame.

MY was helping MQ in the workshop with his wooden frame as he would use the same procedures in the construction of his frame. These students may have gathered the idea from the teacher (during the process testing in Stage 1) to use three sheets of plywood glued and clamped to make their frames. Whether the assembly of laminated woods had enough strength to hold their weights without breakage was questionable, and was not taken into immediate consideration by the students. Maybe the teacher's experience (expert) with materials helped the students (novices) to determine the thickness to meet the required strength. The teacher encouraged the students to draw a new sketch (free hand sketching) of their frames on a sheet of paper in addition to the design notes to demonstrate their thinking. Students were helping each other and sharing useful information in the workshops while drawing designs, processing and measuring, which lead to problem solving through collaborative thinking.

The procedural knowledge of manipulating materials and its application was evident during the making and finishing of the body pans and frames. Significant amounts of filing, drilling, bending, aligning, welding, marking, cutting, laminating and sanding was carried out in the workshop. An example of this from the workshop is that EM was deciding on the final design of his frame and adjustable footrest with three pieces of rectangular square sections by referring to his cardboard pattern and using trial and error alignment of the bars (see Figure 5.11). His frame was designed to be adjustable to accommodate the requirements of the student and his stakeholders. He mentioned that he would have to weld the two pieces together so that the third small rectangular section could slide in and out to give an adjustable footrest and wheels so his stakeholders could also ride the luge as shown in the Figure 5.11. Innovative ideas can emerge while students design and make in a technological design context. The innovative idea was acknowledged by the teacher by providing expert advice on design to EM.

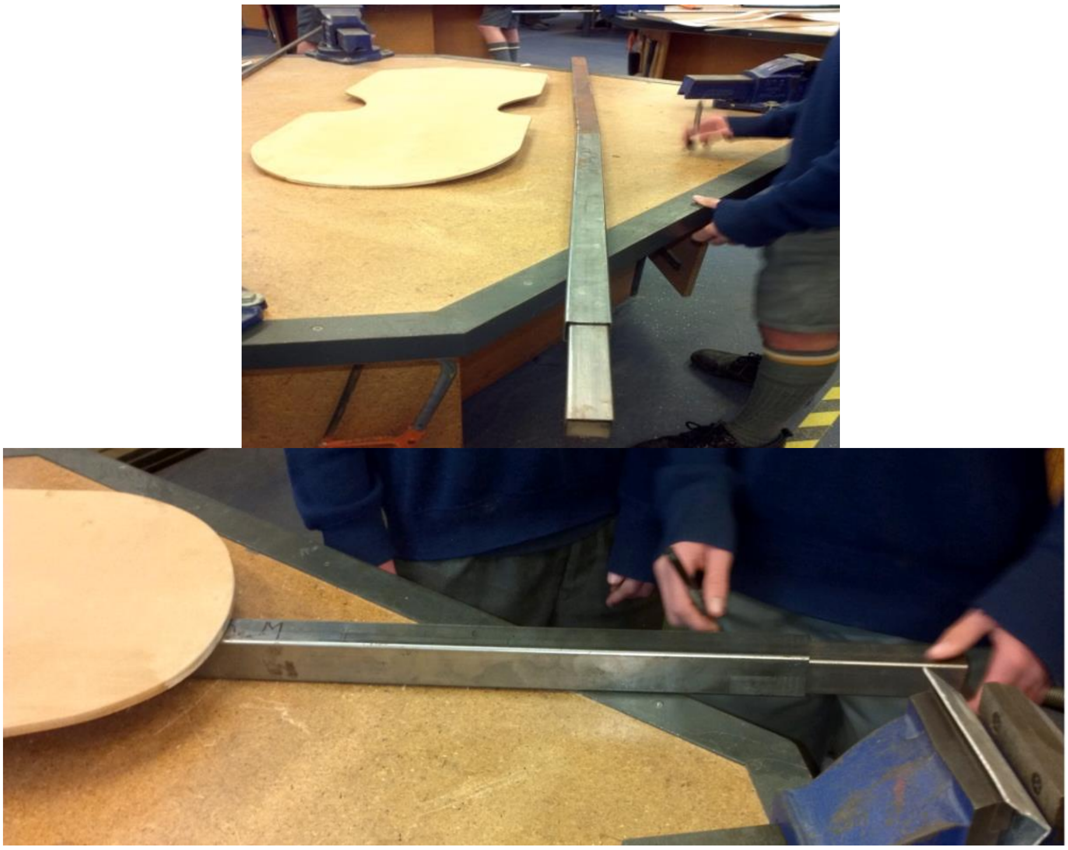


Figure 5.11 Three rectangular sliding steel sections for frame and footrest.

The researcher observed considerable collaboration and sharing of information among the students in the workshop. This was in the form of working together and helping each other to achieve the desired bending of the frames. In a way the students were collaborating among themselves and with the teacher to achieve their goal of making the luge. For example, MQ was helping JC with his wooden frame, providing instruction on how the curves need to be formed along the wooden frame. It seemed as if students had developed their own understanding regarding the placement of the wooden blocks beneath the wooden frame to give the required elevation on the frames (by recalling the lamination of plywood from Stage 1) as seen in Figure 5.10. The teacher did not, at the time, give MQ any instructions on how to achieve the required elevation personally, but the student could successfully recall the manipulative technique from Stage 1. The general technique of laminating plywood was demonstrated to the students during Stage1 without specific application. MQ managed to recall the technique and could apply it to laminate the plywood to the desired measurements to fit the body pan. A point at a distance of 18 cm from one end of the frame was marked and a wooden block was placed just beneath this point and clamped by MQ to achieve the required elevation as shown in Figure 5.10.

Students who developed understanding through trial and error and from the teacher gave demonstrations to a group of two or three other students to pass the information. An example of this is the transfer of information on achieving the desired elevations on the frame passed on to other students in the workshop during demonstrations carried out by MQ and JC. The teacher commented that MQ may have developed this understanding by referring back to his cardboard pattern and Stage 1 process testing. Thus, considerable problem-solving skills and transfer of process knowledge were demonstrated by the students to decide on the structure and elevation for their frames through cooperation and collaboration amongst themselves. And the teacher promoted this by facilitating students' demonstrations to each other, indicating that the role of an expert can also be taken by a student.

There were instances where the students' interaction with the materials stimulated ideas about the structural integrity of the luge. For example, MQ decided to test the weight distribution on his luge with a pilot lying down on his loosely assembled luge. MQ fixed the components of his luge assembled (body pan, frame, trucks and wheels) and asked MY to lie down on the body pan to check where bending was occurring in his frames. This provided MQ with an idea of where the weak points in his frame were and the areas he needed to strengthen. MQ indicated that he would be testing for weight distribution by changing the positioning of the wheels at a later stage to accommodate the bending of the frames.

The teacher played a vital role as his experience and knowledge provided deeper insight into the understanding of luge design leading to accepting/rejecting/formulating/modifying student ideas regarding alignment of the frames with body pans. Some students had already started thinking ahead about their head-rest and nose cone during these sessions. The teacher cautioned that their first priority should be to get their chassis mobile before they started to work on their head rest or nose cones. The first step towards making the luge mobile was to fix the wheel set using truck plates on to the frames. Truck plates are simple rectangular steel plates which provide a rigid connection between the wheels and the frames. Instructions were provided to the students in terms of making their luges mobile by positioning of the truck plates for optimal steering and a smoother ride. The teacher highlighted the procedure in the workshop:

> [DC] is not far away at the moment from being mobile, he just needs to do the trucks and once he has got the thing mobile, then you can put the braces in where you think they need to go and mount your back truck plate. Once you have got your back truck plate mounted, then you can determine your weight distribution by moving your front plates backwards and forwards. (Teacher, Classroom Recording Stage 2)

Information on screwing the body pans to the frames using various bolt sizes was also provided in the workshop. Students made reference again to their cardboard patterns to align them with the loosely assembled body pans and frames to determine the required length of the frame and the positioning of the truck plates.

5.1.4 Truck Plates for the Wheels

Not all the students progressed at the same pace, so some students started working on their truck plates luge. The teacher distributed a hand-out which detailed the sequence to follow and an orthographic drawing which provided the specifications and measurements students were required to take into account while making the truck plates. The sheet mentioned the plate dimensions with a tolerance of + or – 0.5 mm (see Figure 5.12). The making of truck plates involved many measurements utilizing datum lines and drilling holes of specific diameters after cutting the plates according to the requirements. Points had to be marked out to be drilled by considering the lines of symmetry and external measurements (see Figure 5.12, 5.13 (a) and (b).

The following components are to be manufactured as part of your assessment for A/S 1.20.
Work from the sequence sheet and orthographic drawing supplied.

	Complete the following stages to manufacture the truck plates from this orthographic drawing.
1	Select plate materials and file to correct overall size. Tolerance = + or - .5mm
2	Mark out all 8mm holes. Tolerance = + or - .5mm. Pre check and drill
3	Mark out all 5mm holes. Tolerance = + or - .5mm. Pre check and drill
4	All external corners to be finished with a 10 mm radius.
	Materials List
5	2 x flat strap 65/3 mm. Starting size 123mm

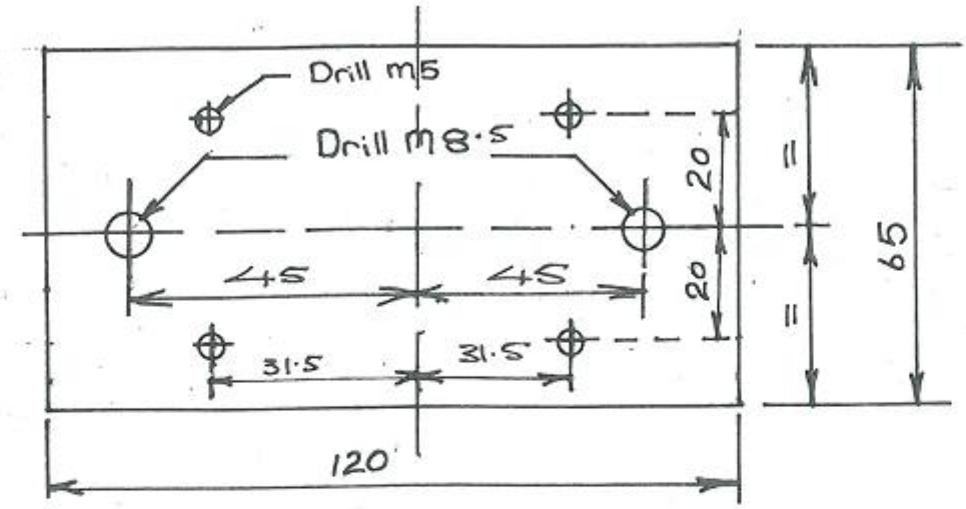
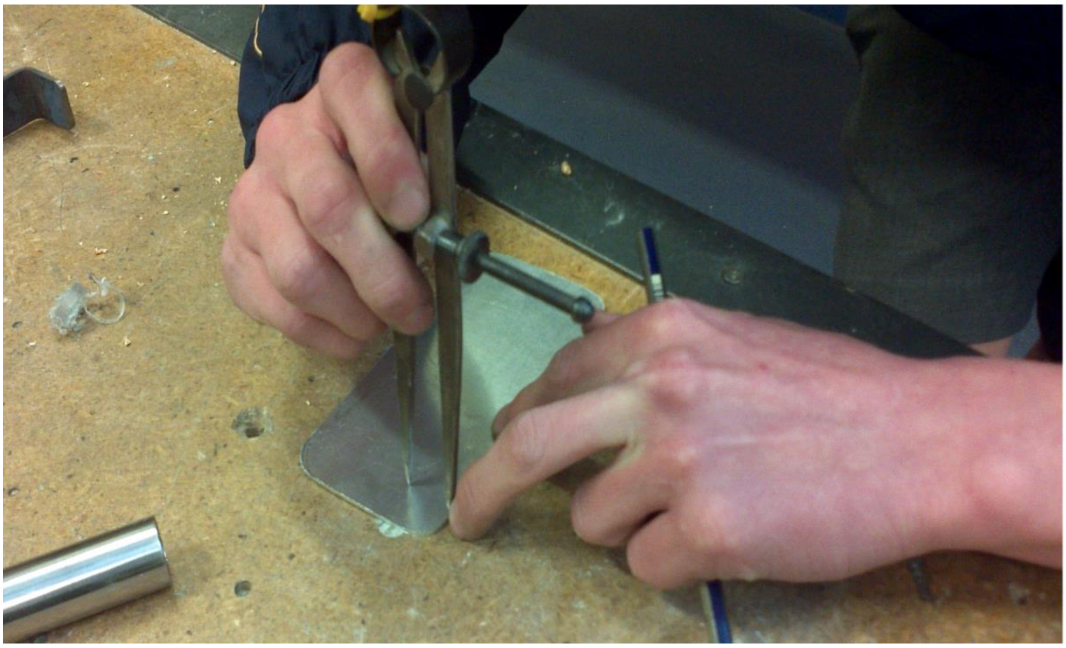


Figure 5.12 The sequence and orthographic sheet for truck plates.

A difficulty encountered by the students while making the truck plates was measuring and filing the piece of metal to the required dimensions with opposite sides being parallel, requiring patience and hard work. The dimensions specified by the orthographic sheet were customised for bolting the wheel set to the truck plates. This involved careful measurements with considerable attention on filing the truck plates which the students found frustrating and time consuming.



(a)

(b)

Figure 5.13. (a) Use of compass to mark points and arcs, (b) Marking and measurements while making truck plates.

Students were trying to mark the position of their truck plates on the frames and this involved thinking about attaining maximum stability for the luge. At this stage, the teacher realised the need to discuss information regarding weight distribution.

5.1.5 Positioning of the Wheels: Weight Distribution

Instructions and information related to weight distribution on the luge were provided to the students in the design room. The teacher explained the need for getting the right weight distribution:

> To make these things steer properly, you need the maximum weight or more weight on the front wheels than the back wheels because the front wheels are the ones which are going to do all the steering and the back wheels just trail on behind and pretty much holds [sic] your head above the ground. (Teacher, Classroom Observation Recording, Stage 2)

The teacher introduced the weight distribution rule of applying 60 percent of the weight on the front wheels and 40 percent on the back wheels. This information was gathered by the teacher from the internet and he thought it was appropriate to provide it directly to the students. The procedure of getting the correct weight distribution involved calculations by the students, taking percentages and ratios of the total weight. The process of finding the correct weight distribution was then illustrated to the students on the white board by the teacher:

> Just put a couple of screws in your deck to hold your luge in place for the time being and jump on the scale with all your bits and pieces. So you will get a weight of yourself with your luge which might be something like 80 kg altogether. Now, the next thing is, we are going to do a little calculation there to get our percentages, the easiest way for me is to do this to divide the total weight by 10 which gives us 8kg; and then multiply it by 6 to get 48kg, so that is what we have on the front, and 8 times 4 to get 32kg. Okay, so when we add them together we got our 80kgs. We just go back to our percentages, divide our mass by 10 and then multiply it by 6. We have got our calculation now, so we have got 48kg on the front and 32kg on the

> back and the next thing we do is we just get our set of scales to get the position of the trucks. (Teacher, Classroom Observation Recording, Stage 2)

The mathematical calculations were done on the whiteboard by the teacher to provide an understanding of the 60:40 rule for weight distribution. The teacher proceeded to provide further instructions on to the placement of the truck plates and wheels on the frames to get the correct weight distribution for the luge. He instructed the students as follows:

> Put your board on the ground with a block on the back approximately where you want to put your trucks at the back. The next thing you do is to put a block of wood at the front of your luge and put the scales underneath it and look for the measurement on the scale. Let's not worry about the back one because if we get the measurements right on the scales for the front one, then it must be the other measurement at the back because we haven't got any extra weight. (Teacher, Classroom Observation Recording, Stage 2)

The purpose of the instructions was to provide students with an idea about the importance of getting the correct weight distribution using mathematical calculations. Students were paying attention during this session and it seemed that they understood what was being taught. JS had a subsequent discussion with the teacher in the design room as seen below.

JS: I am not arguing with you or anything but I thought it was 50:50 with weight distribution?

T: If you can find out and prove that it is 50:50, then it is fine. All the information we have gathered over the years have [sic] said 60:40 and that kind of makes sense to us because you are trying to put more weight on the front wheels so you get them to steer better.

JS did not seem to be satisfied with the answer provided by the teacher but decided to follow the instructions. This indicates that the student thought about the concept of distribution of weight with respect to his luge. The students went back to the workshop to work on their body pans, frames and head-rests. They were now highly motivated towards the completion of their luge and considerable collaboration was going on among students in the workshop.

The majority of the students started to work on their weight distribution within a week or so of the procedure being explained to them in the classroom. But students like MQ followed the procedures soon after the instruction. MQ finished bolting his truck plates onto the frame after his weight distribution was taken into consideration. He followed the procedures and performed the calculations involved in determining the weight distribution in the workshop.

However, BA was confused about the whole procedure of getting the weight distribution done. He was not sure why he was taking the whole weight into consideration to position the trucks. He approached the teacher to seek help with the weight distribution process, but the teacher directed him back to the researcher as the teacher was busy helping other students with the welding process. The researcher helped the student with the weight distribution process including recording total weight, calculating percentages and the positioning of the blocks. The total weight was recorded on the scales (See Figure 5.14) and calculations were performed with the assistance of the researcher, also making sure that the student understood the procedure. BA did not want the values to be precise while lying down on his body pan as he was afraid he might break the assemblage by applying his full weight. BA marked the approximate positions of the blocks where his trucks needed to be fixed. This process gave him an idea of where his trucks needed to be and going through the process made him aware that the maximum weight has to be on the front wheels. The student understood the instruction provided by the researcher but could not carry out the weight distribution procedure by himself.

Figure 5.14 BA getting the total weight on the weighing scales to perform calculations and the weight distribution process.

The teacher was constantly pushing students to work towards the completion of their luge as they were running out of time. Once the project was mobile, students could then start to think about their head rest and nose cones. Then it was just a matter of finalising the painting and other minor processes like bolting the hand rests. The role of the teacher as a facilitator helped students to solve problems when confronted with them. The teacher conducted demonstrations to the whole class on the technique of polishing the truck plates.

It only became evident in the workshop that, not many students understood the teacher's explanation of weight distribution as they asked the researcher for assistance in the workshop. The researcher helped SS and HM through their weight distribution procedures and calculations in the workshop. Initially, SS demonstrated no understanding of the weight distribution rationale or procedure. The researcher first repeated the rationale for carrying out the weight distribution to SS and proceeded to demonstrate the procedures involved. Measurements were made again on the student's behalf by the researcher. The researcher also helped SS in marking the position for his truck plates by recording and adjusting the values on the scales (60% of the total weight). Towards the end of the procedures, SS understood that maximum weight has to be placed on the front wheels. HM was watching the whole process but still requested help from the researcher for calculating the percentage of his total weight.

DR was trying to ride his luge in the workshop but, maybe due to miscalculating weight distribution procedures or selecting the wrong materials for his frame, his luge was sagging close to the ground which would affect the steering and smooth riding of the luge. DR was advised to carry out the weight distribution process again to check his calculations. The researcher was not sure if DR really understood the logic, but he successfully progressed through the stages. DR repositioned his trucks at a later stage.

Similarly, the researcher helped NT to carry out his weight distribution calculations and mark the position of the front wheels. NT had no idea about the whole purpose and procedures of the weight distribution. The researcher explained the purpose of weight distribution again and took NT through the procedures. His total weight along with the luge was measured but NT was unable to calculate 60 percent of the total weight. On being asked, NT simply commented:

> I don’t know, I am not good with maths. (NT, Informal classroom conversation, Stage 2)

Sufficient support was provided to EM, JS and JC to calculate their weight distribution again in the workshop. Initially, DR did his weight distribution by himself but may not have taken the 60:40 distribution rule into account. It took a few weeks for DR to redo his weight distribution and he managed to re-fix the trucks to newly marked positions which provided a much more effective ride than originally. The procedure of calculating the weight distribution seemed to be problematic for the students as they could not apply the procedure and perform the mathematical calculations in this real context.

The next step for the students was to design and make the nose cone and head rest.

5.1.6 Nose Cone and Head Rest

The teacher spent considerable time in the design room talking about the different shapes of the nose cones and head rests designed by the previous year's students. The teacher encouraged the students not to copy previous designs but to be innovative in making their own shapes with the appropriate materials. The teacher instructed the students in the design room:

> One of the problems that we have is that people look at the existing stuff and they kind of think that is good enough for me and a lot of the times it is not. We always try to develop things so they look different. (Teacher, Classroom Observation Recording, Stage 2)

The teacher displayed the nose cones designed and constructed by previous students and talked about their functions, materials and design faults. This was to make students think about the designs for their construction. The teacher instructed the students to design their nose cones first on paper for the teacher to inspect and suggest modifications before they made them.

MQ drew his nose cone design on a sheet of paper and took measurements from his design to cut a length of steel tube after considering suggestions by the teacher. MQ started to work with the exact measurements for his nose cone from the design sheet (see Figure 5.15). Other students also drew their nose cone designs on paper first and then had them checked and sometimes modified by the teacher, whose expertise and competence influenced the designs. The teacher was motivating the students continuously to get the work done in the workshop as they were running out of time for completion of the luges. The teacher also talked of the importance of making the luges aesthetically pleasing. The teacher mentioned that the design, look and functionality of the luge would be inspected by engineers on race day.

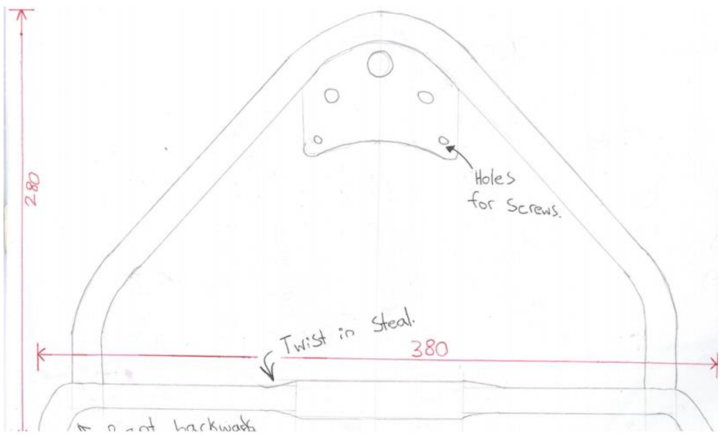


Figure 5.15 MQ's nose cone design taken from his technology portfolio.

Students were lying on their luges to identify the positioning of the nose cone and footrest. The use of mathematics as a tool was prominent in the workshop in the form of basic calculations. Compasses were used by the students to mark arcs on to their truck plates. A few students also asked the teacher about the procedure of welding two pieces of steel tube at an angle of 45 degrees to each other. The teacher gave appropriate explanations to the whole class using set squares, protractors and techniques of drawing parallel lines. Students were working on their nose cones and trying to place them symmetrically on the chassis. This was accomplished by using T-squares and rulers. Achieving the desired look and checking for symmetry was carried out extensively in the workshop towards the end of Term 3.

Students took into account the requirements of the stakeholders while making the nose cones and footrests by making continuous reference to the cardboard patterns. For example, MY finished the construction of his footrest and started to work on the head rest. The footrest made by MY (see Figure 5.16) was adjustable, which accommodated the requirements of his stakeholder. MY also made a cardboard pattern for his head rest and made regular references to his luge using the pattern during his design.

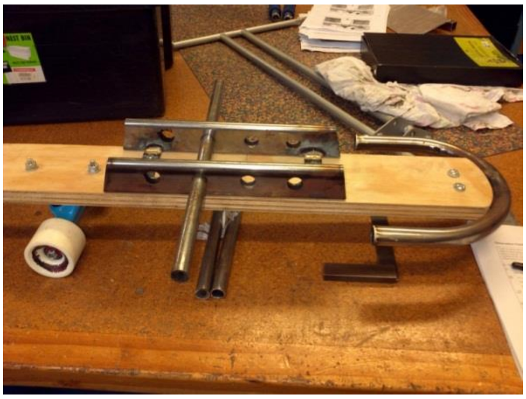


Figure 5.16 MY's adjustable footrest, achieved through problem solving and interaction with the luge components.

MY spent considerable time choosing the appropriate materials required for making an effective nose cone as evident in Figure 5.17. The teacher observed and noted that the initial ideas of their design were changing once they started to think in terms of the materials and their effective use.

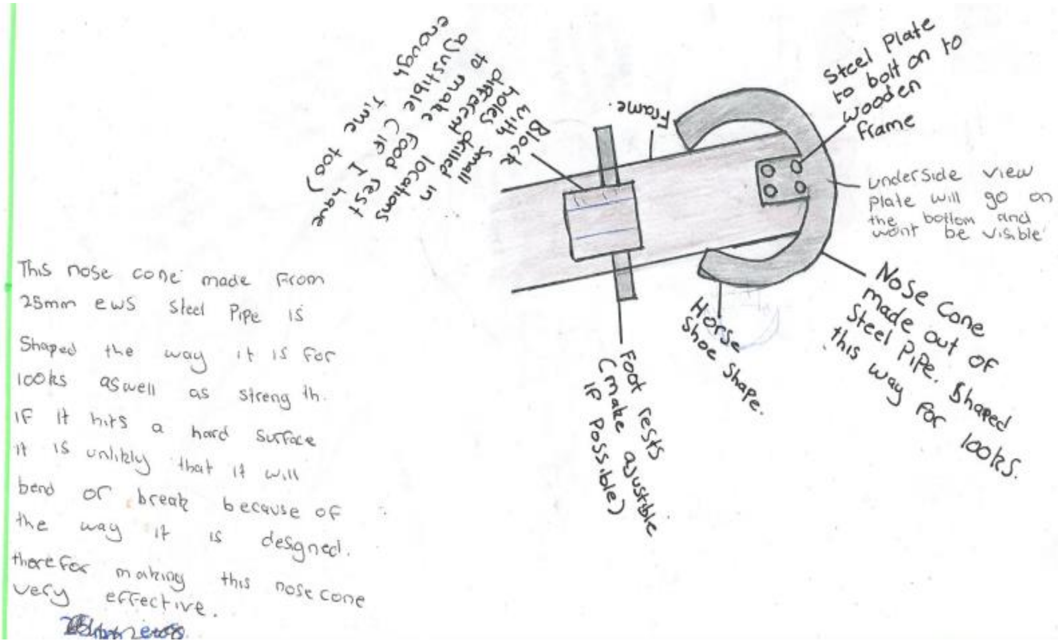


Figure 5.17 MY's annotated nose cone design.

The procedure of bending aluminium sheets using a bender was demonstrated to the students in the workshop. Aluminium was chosen by most of the students as the material appropriate for their head rest. Students were more focused on making progress than before and there was no loss in the motivational level during these stages as they were nearing completion.

Many measurements and much checking for symmetry was going on in the workshop during the designing and making of the nose cone and head rest. Figure 5.18 shows the nose cone designed by MY which involved considerable checking for symmetry to align well with the frame and to make sure that the luge was well balanced.

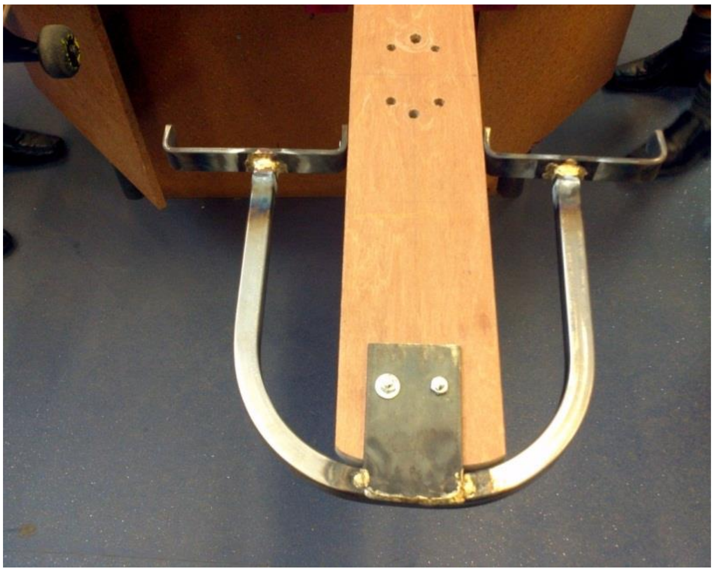
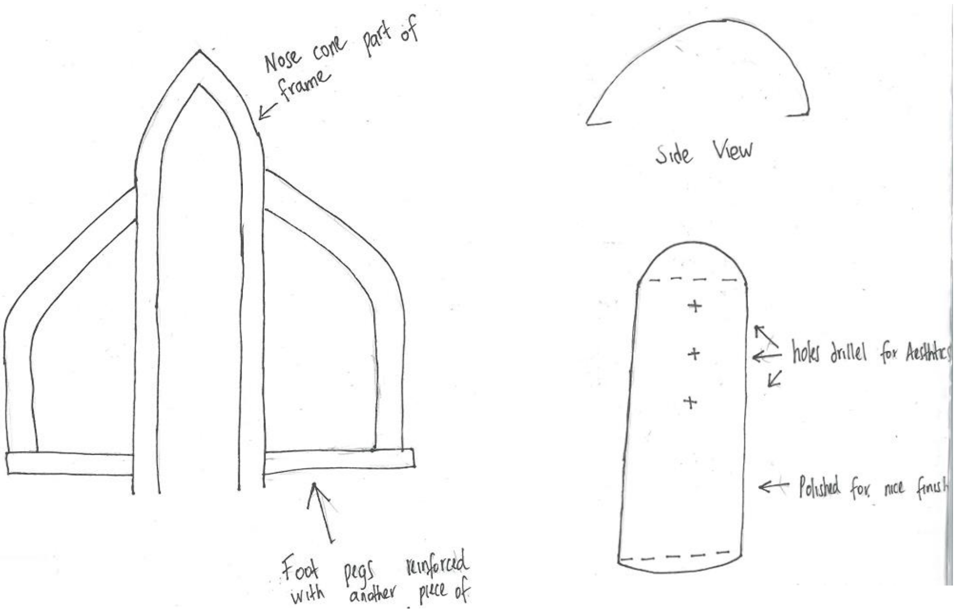
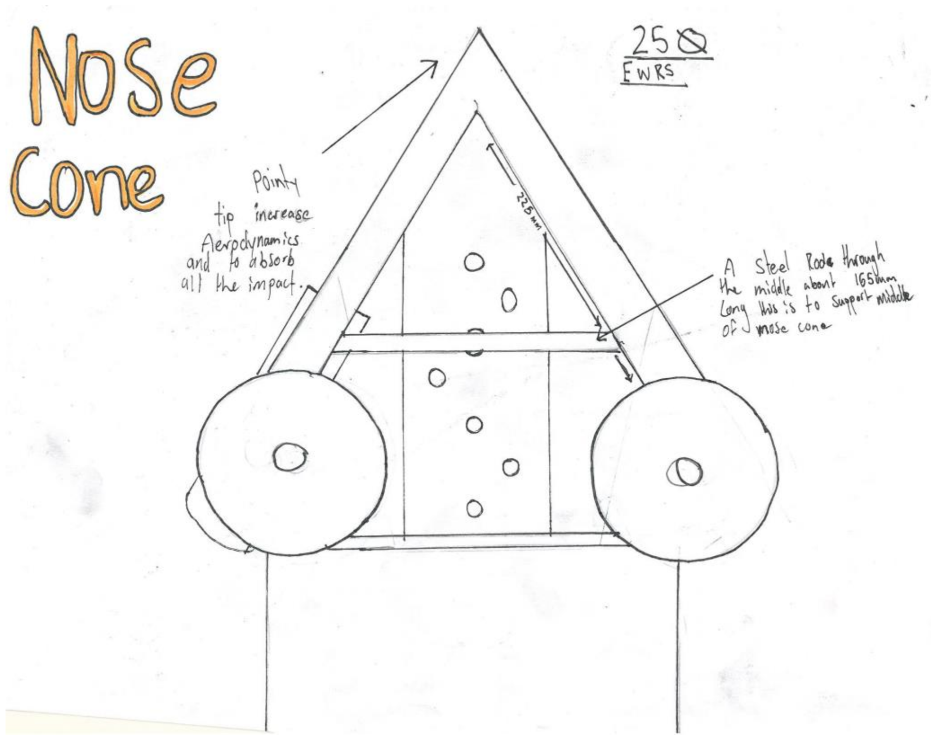


Figure 5.18 Nose cone design welded and bolted symmetrically to the frame.

Students designed their nose cone and head rest first on paper but made continuous references to their constructed luges and those that had been constructed in the past. A few examples from the student portfolios of the nose cones and headrest designs are shown in Figure 5.18 (a) and (b) which illustrates the factors students referred to while designing, such as the selection of material, and the processes for manipulation. A reference to the principle of aerodynamics was also made by TJ in his annotated diagram in Figure 5.19 (b). TJ considered that the pointy tip of his nose cone would reduce aerodynamics. It is worth noting at this point that no evidence could be found of other students who made references to the concept of aerodynamics while designing their nose cones. It can be said that the particular student explicitly recalled the knowledge he gathered during Stage 1 and applied it while designing the nose cone.



(a) TG nose cone and head rest concept design



(b) TJ nose cone concept design

Figure 5.19 Concept drawings of the nose cones and the head rest from TG's portfolios.

The students started to work more independently towards the completion of the project in Term 3 and were helping others who were still working on their luges. At the end of term, there were three or four students who were still working on their handgrips and needed to complete the painting of the frames and body pans. The final stages of the project involved the assembling and fastening processes of the luge components as the students were required to participate in a trial race before the race day. A majority of the students finished working on their luges towards the end of Term 3.

5.2 Experience and Perception of the Students in the Workshop

During the frame construction phase, the researcher discussed with a number of students their perceptions of utilising concepts from science and mathematics during the construction phases. For example, the researcher asked LG regarding the sort of knowledge he used from science or mathematics while making his luge. LG said knowledge from mathematics was applied for example, for measurements and determining if the angles were correct. LG considered science to be incorporated through the determination of the weaker sections of the frame through inspection and the improvement of the overall quality of the frame by adding metal joints to prevent snapping while riding. LG determined the sections where stress (a terminology used by LG) due to the weight of the pilot will have the most adverse effects like bending or collapse. BA mentioned that measurements using rulers, bending and determining angles were extensively used. However, he was not quite sure about the science. MY said he used mathematics in the form of basic measurements, which was hard but eventually it was successful. The use of mathematics as identified by MY was in finding the right weight distribution of the luge. NT commented that mathematical measurements were the hardest part of the process he encountered while designing and making the luge.

The researcher had a conversation with SS about his experience of first time designing and making in a technology classroom. He indicated that it was confusing for him at the start and he knew little about what to expect and do in a technology classroom. However, as he began his work in the workshop, SS started to learn about the processes and manufacturing side which he found fascinating and which motivated him in the construction of his luge. He indicated he may take technology in the following year as he enjoyed doing practical things. The practical aspect of technology and the motivation to do so was a key factor in completion of the luge. For example, MY also commented that he could not believe he finished the luge on time. MY was facing practical difficulties in processing and applying calculations while making the luge in the workshop. This may to some extent explain his relief on completing the project.

5.3 Summary of Chapter

This chapter provides an insight into the practices and perceptions of the teacher and students working in a technology classroom. It can be said that the focus was on developing a functional product and the students were interested in acquiring knowledge and skills to that end. This involved considerable planning in terms of materials and material properties as students started to work with the materials to develop their product.

The evidence indicates that science and mathematics were applied during construction of the individual components. The application of science was observed while the students worked on shaping and assembly of the luge components and remains implicit with the procedural knowledge in technology. The application of mathematics was extensively observed as students designed and made the luge components.

Chapter 6 will present the findings from Term 4 where the students raced their luges against other schools. The data from the focus group and teacher interviews relating to the practices of the students as they designed and made their luges are also presented.

CHAPTER 6 – STAGE 3 OF LUGE TESTING

6.0 Introduction

This chapter presents data from Term 4, which includes the testing and evaluation of the street luges from the race day and examines and triangulates data from student focus group interviews, student questionnaires, teacher interviews and student portfolios. This chapter is focussed on presenting the perceptions of the teacher and his students regarding their own practices and the integration of science, mathematics and technology in the context of luge design. Questions were devised to obtain a detailed picture of the integration of science, mathematics and technology during the designing and construction stages. Suggestions for improving the classroom experience in terms of integration were also provided by the teacher and students during informal conversations and interviews.

In the next section, data will be presented from the race day followed by student focus group and teacher interviews, student questionnaires, and the testing and evaluation report from the student technology portfolios. This sequence will take the reader through a chronological sequence of events which took place in Stage 3. The data from the technology portfolios (testing and evaluation reports) will also be presented in this chapter and triangulated with the focus group interviews (students), classroom observations and the final teacher interview.

6.1 Stage 3 - Testing and Evaluation of Street Luge

Students were expected to race their luges with two other Hamilton-based schools. The luges, along with the appropriate riding gear, were transported to the race track by the parents/guardians. Students were provided sufficient time to perform trial runs in order to get accustomed to the track before the race. The race winners were selected by recording the shortest time that a student took to complete the down-hill track in three consecutive runs. Three engineers from a local council were invited to observe the variety of luges and to determine the best luge design. The students spent the entire day in the park, racing and playing with their luges on the track.

The final task assigned to the students by the teacher after the race day was to write an evaluation report commenting and critiquing the specifications and attributes they choose for the manufacture of the luge. The teacher instructed that the report was to also include problems faced by the students while testing their luges and their approach towards solving these problems on race day. Conclusions were also to be included in the student reports to indicate satisfaction with the performance of the luge and suggestions to incorporate future improvements.

Focus group interviews with the students and the final interview with the teacher were conducted towards the end of Term 4, after race day. This provided sufficient time for the students to test and evaluate their luge on the race day. Students were selected randomly from the classroom in five groups of three to four for the interviews to be conducted during the technology class sessions (see Table 6.1). The focus group interviews were conducted in the workshops (in a silent environment) with the students sitting in close proximity so they could discuss the questions and the comments and ideas of other participants. Each focus group interview began by highlighting the goals of the interview. Not all students in this class where interviewed due to time constraints and the absence of some students from the classroom near the end of Term 4. Fifteen out of nineteen students were included in the focus group interviews. Students were asked to identify explicitly the science and mathematics information that was used in the design and construction of the luge. A final teacher interview was conducted with a focus on the identification of science and mathematics in the context of luge design and identifying improvements and strategies for integration in future technology classrooms. The teacher interview was carried out after the student focus group interviews.

Table 6.1 Focus Group Interview: Student Allocation

Group	Students
Focus Group 1	MY, LG, EM
Focus Group 2	TJ, HM, BA, SS
Focus Group 3	MQ, TJ, JC
Focus Group 4	JS, JV, NT
Focus Group 5	JP, ST

Table 6.1 shows the allocation of students to the focus group interviews. The interviews took between 30-40 minutes. The next sections will present the data from the student focus group interviews and final teacher interview where they were

asked to identify the science and mathematics at various stages of the project, the first stage being Momentum testing.

In the following sections the data from the student portfolios will be used to describe their understanding of science and mathematics with their practical understanding of the product. The focus group interview was conducted by displaying printouts of scanned documents from previous year student technology portfolios and pictures taken during the construction phases to simulate student thinking and recall ability to answer questions.

6.1.1 Momentum Testing Phase

Momentum testing was carried out in Term 1, where investigations were performed with the appropriate controls aimed to study the relationship between variables like wheel sizes (50mm, 70mm and 100mm diameter) and driver weight (45kg; 110kg) on the speed of the luge over the set distance. In the focus group discussion, none of the students could recall using any science concepts when they did the momentum testing in Stage 1. HM, TJ and JC mentioned calculating average speed for heavier and lighter pilots during the momentum testing phase. No evidence was found in their technology portfolios that they had calculated average speed. The students might have been referring to average time in their portfolios while writing conclusions. This might be a slight misapprehension on the student's part. JC highlighted the mathematical calculations performed during this phase like recording various times and averages in order to find the shortest travel time. These calculations enabled the students to make judgements about the selection of the fastest set of wheels (70mm diameter longboard) and the effect of the weight of the pilots on this chosen wheel set (70mm diameter wheel) to achieve optimal speed for the luge. The use of mathematics to perform basic calculations was evident from the following responses (focus group interview) which enabled the students to make conclusions in response to the researcher's question:

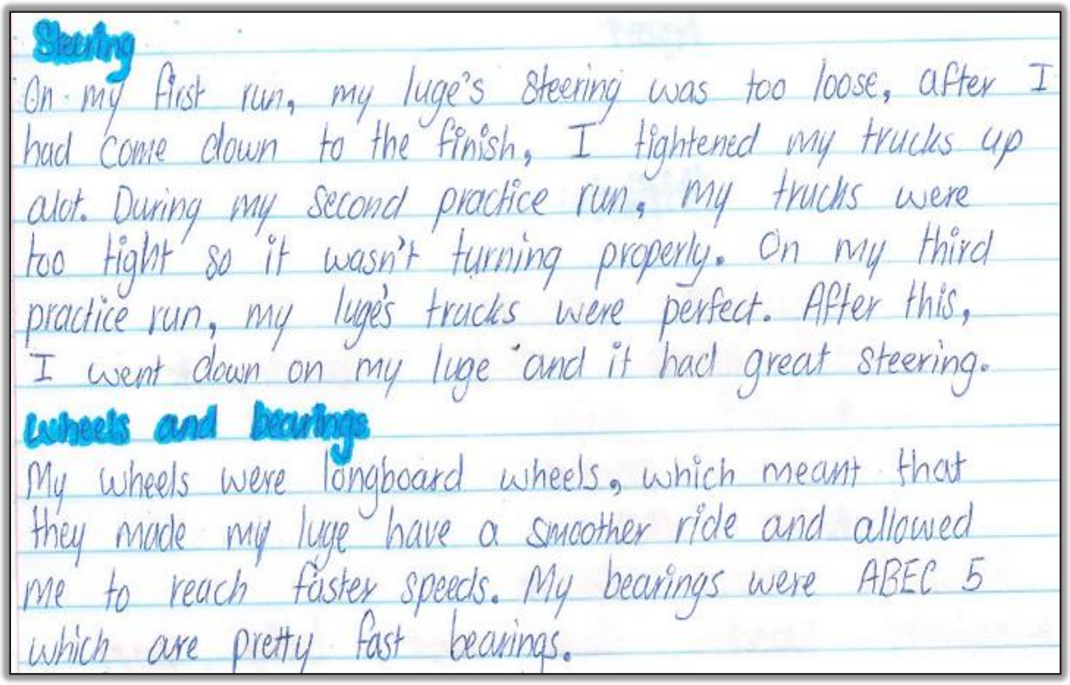
> HM: Calculate the average speed for heavy pilot and light pilot.
>
> TJ: I think there was this tiny bit maybe the speed, like working out the average speed with distance over time.

JC: Yes. Taking a look at all the different times you got and say this one has got a lower time so it is faster.

The teacher recognised that presenting much information from science at this stage may not be beneficial since they are at the initial stages of the project and considering they are only Year 11 students. The teacher also identified that he grappled to explain scientific theory like momentum and forces in the context of the luge design. The teacher wanted to give the students an opportunity to do experimentation by testing the variables of wheels and weight on the speed of the luge where they can relate the basic science they learn in isolated classrooms to the context. Even though the teacher wanted the students to relate what they do in technology to science, the evidence suggests that the students were not able to recall any science concepts they utilised at that stage (momentum testing). This might suggest that the students were not aware of their use of science and mathematics principles to explain their conclusions. The teacher noted:

> They are testing their theories by putting them into practice in their luge and there are so many other variables with the luge like speed and steering and they may not work, so it was just a process of getting them engaged and to make them understand the issues they are going to deal with and how to deal with them. (Teacher, Final Interview, Stage 3)

This investigative approach enabled the students to make decisions based on the available data as evident from the conclusions drawn in the technology portfolios which have been shown in Stage 1. The correct selection of wheels provided a smooth ride, as noted by the students in their evaluation reports. These reports confirm the wheel set chosen by the students and discussed the problems faced with their wheels and trucks which affected the steering ability during the initial trail runs. Students faced the issue of speed wobbles during their first runs, but overcame this by tightening the trucks. This procedure of tightening the trucks was carried out by almost every student in the classroom in order to get rid of speed wobbles and to achieve higher speeds by reducing ‘friction’ (see Figure 6.1(b)). The tightening of truck bolts leading to reducing ‘friction’ is questionable. The excerpts from student portfolios which appear in Figure 6.1 indicate the practical understanding developed by the students after the race day. It is interesting to note that the students were able to identify the mathematics involved and utilise them in their luge project during the focus group interviews, and they were also able to demonstrate a practical understanding of their product, but they could not identify any science. The students demonstrated going through a process of trial and error to achieve an optimal speed and satisfactory riding experience (see Figure 6.1 (a) & (b)). This allowed the students to solve practical problems by themselves as they encountered them on the race day as demonstrated in the excerpts in Figure 6.1 (a) and (b).


Steering

On my first run, my luge's steering was too loose, after I had come down to the finish, I tightened my trucks up alot. During my second practice run, my trucks were too tight so it wasn't turning properly. On my third practice run, my luge's trucks were perfect. After this, I went down on my luge and it had great steering.

Wheels and bearings

My wheels were longboard wheels, which meant that they made my luge have a smoother ride and allowed me to reach faster speeds. My bearings were ABEC 5 which are pretty fast bearings.

(a) DR's evaluation of steering and wheels

WHEELS On the race day my luge wheels performed well. With slight adjustment I was able to increase the speed of the luge by loosening the nuts on the trucks and decreasing the amount of friction being applied to the wheels .

TURNING At the beginning of the race day my trucks were too lose and I was getting major speed wobbles. As a result of this I had to tighten the trucks and I was able to make it around the corners without spinning off the track.

(b) EM's evaluation of wheels and turning effects

Body Actuated Steering

The body actuated steering work almost perfectly, although while going down the track there was some small speed wobbles. This problem was fixed by tightening the kingpin on my trucks. Another problem I ran into was that the turning was very sensitive, this problem can be overcome by replacing the trucks with longer ones.

(c) JC's Evaluation of wheels

Turning: When trailing my luge, I found out that the steering mechanism did not do as I expected; when I leaned to one side it would turn too sharp and that gave me a chance of crashing. To accomplish this problem, I got a spanner and tightened the truck bolt until it turned properly again.

(d) BA's evaluation of wheels

Wheel and bearings
What makes a luge go faster are long board wheels and good bearings. These types of components made my luge go down faster during my first practice test on the race day. I realised as well that skateboard wheels don't run down as smoothly as longoard wheels does, like what I have seen with other students with them.

Steering
On my first practice test with my luge I have realised that my trucks were to lose that I have gained speed wobbles as I go down the hill. What I did after my test is I had to tighten up my truck so I will have an easier control with my luge. As I went down for my second practice test I didn't experience anymore speed wobbles.

(e) SS luge evaluation of wheels and bearings

Figure 6.1 Excerpts from luge evaluation reports from various students commenting on the wheels and body actuated steering.

The body actuated steering was adjusted during the trial runs by tightening the truck bolts (see Figure 6.1 (a) & (b)). The testing of the luge provided an opportunity for the students to develop a practical understanding of the steering mechanism in addition to the theoretical understanding of body actuated steering gained during Stage 1 (see Figure 6.1 (c) & (d)). The evaluation reports also include a practical rationale derived by the students based upon their observation and experiences. For example, SS confirmed in his luge evaluation that longboard wheels are best suited for his luge, a conclusion derived from the field data (see Figure 6.1 (e)). The student also acknowledged the bearings in the 70mm diameter wheels as a reason for its faster speed. SS concluded in his initial momentum testing phase (Stage 1) that the 70mm diameter wheels were better as indicated by his field results. SS may have then used skateboard wheels initially for the trial, but later decided to use long board wheels as demonstrated in Figure 6.1 (e). This indicates that the luge testing phase and prior component knowledge provided the student with a better practical understanding of the significance of choosing the most appropriate wheel. The steering for his luge was also adjusted based on the tacit knowledge of tightening the truck bolts. It can be seen that students generate technological knowledge when they interact with the product with an aim of designing, making, testing and improving.

It is evident from the Figure 6.1 that students learned to solve the problem of speed wobbles and body actuated steering practically by tightening the truck bolts for stability. This was a practical understanding achieved through trial and error in the field (and in Stage 1) and was adopted by almost all the students as reported in the portfolios. It can be deduced that a majority of students are able to make positive judgements to solve problems with guidance provided by the teacher in technology. The problems students encountered during testing were solved using the tacit knowledge of tightening the bolts.

6.1.2 Luge Research Phase

Students studied the constructed products in the workshop and researched the internet during this phase. This background research in addition to the classroom discussions permitted the students to understand the functioning of the various components and materials to be used for construction of the luge. This was documented by the students in their technology portfolios. Two students (ST & JP) were able to identify the knowledge of centre of gravity as science, which they claimed to utilise while conducting the luge research in Stage 1. For example, ST and JP showed evidence during the focus group of acquiring the knowledge of centre of gravity and as a rationale for bending the frame more towards the ground as shown in this discussion:

> ST: Obviously very much lowered to the ground so that would ….
>
> JP: Affect the steering, like your centre of gravity has to be lower or if you are sitting higher you got more chance of getting speed wobbles and stuff.
>
> R: So while doing your luge research you thought about all this?
>
> JP: Yes.
>
> ST: Yes.

There was no evidence supplied by the students during the focus group interviews of identification or consideration of any science ideas apart from the centre of gravity. The luge research phase was more focussed on the identification of different luge designs, components, functions, materials and processes involved in making the luge. The example of the students above indicates that the information gathered during the luge research phase regarding the functioning and positioning of the luge components provided an opportunity to incorporate science in order to explain the rationale for the assembly of components to form the final product.

6.1.3 Concept Design Phase

The concept design drawings provided students with an opportunity to express their design ideas to decide the shape of the luge and other factors such as materials selection and assembly of the components. Students identified measurements as an application of mathematics in devising their concept drawings. The material testing phase was initiated by the teacher before the students could develop their final concept drawings. This approach helped the students to explore the properties and behaviour of materials during stress loading conditions which facilitated completion of the final concept drawings. TG and JC reflected on the importance of material testing to help them to draw and decide their final concept drawings, taking into consideration aerodynamics and weight distribution as is evident from the excerpts from the focus group interviews below.

> JC: When you draw your design you try to make it aerodynamic.
>
> TG: To see if it can support your weight.
>
> TG: We did materials testing.
>
> JC: And we knew the materials so we decided we can do it this way.
>
> TG: It would be like better one way or the other.
>
> JC: And you just put them into your concept drawing.

This extract illustrates that the students identified these ideas (aerodynamics and weight distribution) as applied science and mathematics and claimed to have utilized these ideas while they made their concept drawings. Using past constructed products to teach and reflect on the shapes of the components was an approach utilised by the teacher in this class. Other students, like NT, JS and JV, did not identify any science and mathematics at this stage. JP and SS displayed evidence in their concept drawings that they considered the placement of the body pans on the frames to make their design aerodynamic with less air drag. JP and SS also confirmed during the interviews that they thought about the idea of designing a streamlined luge to minimise air drag. Mathematics was used in the form of scaling the diagrams to the right proportion and drawing symmetric and parallel lines. BA and TJ also identified aerodynamics and centre of gravity concepts during this phase. BA and TJ provided good rationales and clear understanding around lowering the body pans to the ground, and they took this into consideration while developing their final concept drawings. The 'distance' between the wheels was considered at this stage by HM, which he identified as the application of mathematics during the focus group interviews.

Students were able to identify concepts from science (aerodynamics and weight distribution) and the application of mathematics when they were asked specifically to do so during the focus group interviews. This indicates that, to some extent, the students are able to refer back to science concepts which were discussed earlier during the design stage and to apply them during the construction (Stage 2).

6.1.4 Integration of Tension and Compression Knowledge

The material testing phase was recalled by the researcher during the interviews by showing the students pictures of laminated plywood and deformed steel sections to capture the perceptions of tension and compression. The rich practical experience and enjoyment this phase brought to the students was recalled by MY during the interview. Students are motivated by rich practical experience in technology. LG and MY recalled the importance of the knowledge of tension and compression which assisted them to identify the weaker elements of their luge, for example to provide metal reinforcements or to change the design concept. LG also commended the approach taken by the teacher towards reinforcing the information on tension and compression in the context of luge design as it provided a better understanding of the theory when related to the testing phase. LG made the following comments during the interview:

LG: I think talking about compression and tensile strength helped me a lot, especially the way my luge was designed at the middle point. Having the understanding of when he [teacher] took the tyre apart and said, 'This is where the weights are going to go, and this is where and how it is going to bend,' which made me think, sure, I can stop this and make it stronger.

MY: Same as my luge. In the middle of it was the weakest point so that is partly why I put the heavy steel in front of it to kind of even it out, to make it a bit heavier at the front so it wouldn't just snap.

EM: Also he [teacher] didn't tell us what the problem was, but he gave us suggestions on how to fix it.

LG: If he wrote down about compression and tension and said here it is now apply it to your luge I wouldn't have been able to, but he took us out and pressed some stuff in the press and told us 'That's what happens and it is going to break,' which was very helpful.

The information on tension and compression was considered to be useful by the students as discussed in Stage 1. Some students indicated during the focus group interviews (Stage 3) that the information on tension and compression was being recalled during the lamination of the plywood to retain its curved shape and applied while making their frames. This gives some evidence of the information on tension and compression being recalled and applied to the context of the luge. As mentioned by TG, JC and MQ during the interviews, such information should be provided as and when required, to a level which the students can follow. According to these students, a basic comprehensible understanding of the observed phenomenon (using science or mathematics) will be better than a detailed explanation with extensive science. Students had the following conversation about the appropriateness of such information in technology when prompted by the researcher.

R: Do you need such information in technology?

TG: Yeah! Kind of.

JC: Little bit.

MQ: Yeah! But just a bit.

TG: Probably not that much, as we may not use it.

As an extensive application of this concept, both JS and JV mentioned that they utilised the information on compression and tension to identify the weaker sections in their body pan and frames and so to provide suitable braces to prevent rupture or breakage. ST and JP advocated the importance of tension and compression concepts, and applied this while constructing their frames. ST mentioned that it was good to know this information as he may use it at some stage of design and construction. ST did not use this information. BA, TJ and MH used this information to understand how tension and compression was practical during the lamination of plywood for the body pans. Data from the focus group demonstrates that BA, TJ and HM had a basic understanding of the forces of tension and compression involved in the bending of plywood. The evidence indicates that the information from tension and compression was recalled or utilised by the students during the construction phases of the project.

The information on tension and compression was taught while testing the materials. The teacher interview indicates that integrating the information from tension and compression was a challenging experience in Term 1. The teacher noted during the interview:

> I think it was okay with me, but it was hard for them to understand it and then they got more frustrated as the time went on. Right at the beginning, I just thought it was simple so let's do some testing, but trying to explain that to them, I think they understood, but it took quite a long time. (Teacher, Interview, Stage 3)

The teacher expressed his frustration with the effort it took to make students understand the information from tension and compression again during the interviews, but realised the significance of this information for the students while designing and making the luge. It is evident from the student focus groups that the information on tension and compression was recalled and applied during the construction phases. This is a good example of the application of scientific knowledge in the context of the design, and it illustrates the interaction of scientific knowledge within the practical domains of technology.

6.1.5 Cardboard Patterns

The cardboard pattern provided students with an opportunity to create a full length prototype before they started the construction of the luge. No information or application of knowledge from science was identified or recalled by any student while actually making the cardboard pattern. Calculations, parallel lines and checking for symmetry were identified as the application of basic mathematics. LG mentioned that he was thinking about the right balance for his luge while making his cardboard pattern so as to keep himself stable by finding the best riding position. MQ mentioned that he thought about aerodynamics while making his cardboard pattern. SS and JP were also looking to make the luge aerodynamically stable by customizing the cardboard pattern to the actual shape and size of the pilot. It can be said at this point that the development of the cardboard pattern provided a context for the students to visualise and decide on the assembly of the components in the luge to make it strong and aerodynamic.

There were instances in the workshop where the students identified appropriate use of materials which led to a change in the cardboard pattern. For example, MY and LG made a change to their cardboard patterns while working with them to save materials and to make the luge lighter:

> MY: Mine was a bad change, I cut out the side of cardboard pattern to make it lighter and to make it look cooler because that is what I was concerned about if it is going to be too heavy, and then ended up making it heavier.
>
> LG: Because of my design, it was like two bent L’s like that joining to another set, and I looked at it beforehand and went, I don’t want to see those little L's, so I put them right up close

> and then reconsidering my design, I went that is now going to make the middle too narrow, so I had to think about the best way to structurally make it so no bending or compression may take place.

These comments highlight that during this stage the students were thinking around saving materials and improving the structural integrity of the luge, which automatically brought in the information from tension and compression without initiation. So there is some evidence of the students thinking in terms of science during the development of their cardboard pattern. Even though MY thought in terms of saving materials during the cardboard pattern, he ended up making a heavier luge. All other students from the focus group interviews indicated that they did not change their cardboard patterns while making the luge in the workshop.

6.1.6 Body Pan Construction

The construction of the body pan took place in Stage 2 (Term 2) once the students had enough background information and skills in terms of wheels, materials, components and material manipulation processes. Students were asked to identify any science and mathematics referred to or utilised during this phase by showing them pictures taken during the body pan construction stage. LG identified the points on the laminated plywood where 'pressure' (as mentioned by the student) had to be applied to hold the plywood together for obtaining the desired curve, and was trying to recall the information about tension and compression with respect to the lamination process. LG, MY, EM, TJ and JC could not identify any application of science at this stage (phase of laminating and making the body pan). During the interviews, both TJ and JC agreed that the testing of plywood was performed at 'extreme' pressures (as indicated by the student) from the hydraulic press, so they did not consider the weight of the pilot to have a significant effect of the body pans. This implies that they developed an understanding of the strength of the plywood during the material testing phase and were able to make decisions based on their prior understanding during the making process. This also shows that they gave some thought to the weight of the pilot (size of the force) during the making of the body pan. The term 'pressure' was also used in this context to refer to the weight of the pilot. Measurements in the form of calculations and checking for lines of symmetry were prominent during this phase. During the interview with the teacher, he identified basic measurements, symmetry, angles and proportions as fundamental uses of mathematics during the body construction stage which aligns well with what the students identified. ST mentioned bending the plywood to assist body-actuated steering when asked to identify ‘science’ during the body pan construction.

Students observed and understood the effect of increasing the strength of the plywood by manipulation. The manipulation of plywood also allowed students to observe and save materials they required for the body pan. Manipulation of the shape of the plywood to a curved form was considered to be a significant mechanism to achieve structural integrity of the project by the teacher, as indicated during the interview. This was achieved by taking the students through the tool related practices and manipulative techniques of plywood to construct a strong body pan (curved) for body actuated steering.

The rationale for the curved shape of the body pan was clear to the students during the construction phases (Stage 2). The data from the final student questionnaire also details responses as to why the shape of the body pans was curved, namely to provide more tensile strength to the material. The teacher demonstrated previous constructed luges and made continuous references to the materials and shapes of the luge which helped students to understand the functioning of the body pan. It also assists in force-oriented steering of the luge, providing a comfortable, stable and a secure riding position. The curved shape of the body pan is also aesthetically pleasing as noted by some students.

The body pan served the purpose of holding the pilot and facilitating body actuated steering while riding the luge. Students were asked during construction (in focus group interviews) if they thought about any forces that would be acting on the body pans. MY reported that the information on tension and compression was taken into account while bending the plywood in the workshop. MQ and TG mentioned that they thought about the distribution of ‘weight’ while making the body pans to achieve effective steering. JP and ST considered the aesthetics and a relevant shape for the body pan which could minimise air drag during the construction. No other students provided any evidence of thinking about other forces they considered while making the body pans. It can be seen that the students had a good understanding of the functionality of the components which provided an opportunity to observe the practical application of science and its contextual application in the luge context.

6.1.7 Frame Construction and Its Alignment with the Body Pan

Students were asked to identify any science and mathematics while making their frame and ensuring its alignment with the body pan. They were also asked to identify the forces and weights applied on the frames and body pan once they were assembled. JS identified science in the form of applied thinking around the strength and weight being applied to the chassis to withstand the static and dynamic load of the pilot. JV and JS screwed the frames tight to the pans and strapped and braced them after determining the weaker sections. This indicates grappling with emerging problems can lead to applied thinking with regards to improving the design which could initiate the recall of scientific knowledge. This also shows how students mastered the process of bracing which is a fundamental design element for strengthening structures. JV and JS performed visual inspections of the luge to check for bending and took appropriate action to prevent the design from collapsing. JS, JC and NT acknowledged that they did not consider any forces acting on the body pan and frame assembly at this stage. They just followed the procedures of aligning the frame with the body pan making sure there was enough clearance for the pans.

The researcher did observe conversations taking place among the teacher and students around the identification of the weaker sections of the frame-body pan combination during the construction phases, which indicates the emergence of this technological knowledge when students interact with more knowledgeable others and the product. During the focus group interview, TG mentioned the use of steel straps between his frame and body pan to support the regions identified to carry most of the weight. He then indicated that he did not give much thought to the forces at that stage, but after testing the luge he found that his frame had bent due to 'unbalanced forces'. MQ acknowledged that he overcame this issue by building his trucks not too far away from each other so as to avoid any bending in his frame while riding.

There was an element of trial and error in determining the required bend or elevation in the frames to get the proper clearance from the ground. During the interviews, ST indicated an element of prediction while aligning the body pan on to the frames to get the right amount of clearance from the ground to lower the centre of gravity. JP noted that while making his frames he took into account the positioning of the pilot and the region of maximum applied weight, and then designed his frame to provide enough strength to carry the desired load by placing three steel tubes together beneath the concentrated weight region. JP and ST both confirmed that they considered the forces that would be acting on their frames and body pan. However, JP and ST did not complete their luge project within the school timeframe so no further data were collected from them.

Similarly, LG and EM took into account the positioning of the maximum weight of various sections of their luge and made appropriate adjustments to protect their frames. MY did not consider it significant at this stage to think about the weight distribution on his frame and gave no reason for it. LG, MY and EM all considered forces acting on their body pan and frames while fixing them together. LG mentioned the assembly of the body pan-frame was aided by referring to the constructed luges in the workshop (steel frame). This indicates that the inspection of the previously constructed luges provided assembly and construction knowledge to the students.

Few students mentioned that when they constructed the frames they did not give any thought to the application of science or mathematics. BA, TJ and HM mentioned during the interviews that they used two pieces of plywood in order to make their frames stronger and fit for their purpose. TJ, BA and HM did not identify the application of any scientific concepts while making the frames. BA indicated that he drilled four holes in his frames at equal distances, indicating the use of basic calculations. BA and SS also mentioned that they just fixed the body pan to the frame and did not think about any science or mathematics at that stage. BA noted in his portfolio that he ensured the final product will be strong enough to hold a certain amount of weight by making the chassis strong. This indicates that BA did think about the areas which would bear the maximum weight, but did not identify this during the focus group interview (also SS).

The lowering of the body pan and frames towards the ground was common and was carried out by almost every student in the classroom, except LG. The rationales for lowering the body pan and frames to the ground were discussed in the classroom during luge research and while inspecting constructed luges in the workshop. The data from the student questionnaires indicated a sound understanding for lowering the body pans closer to the ground in terms of the centre of gravity and aerodynamics (Stage 2). Student responses to the rationale for further lowering the body pans to the ground included reasons like aerodynamics and stability so the luge could attain higher speeds. The rationale that lowering the body pans can lead to a stable and controlled ride is logical but whether such a design would enhance aerodynamics is questionable. This also indicates that students' application of the concept 'aerodynamics' was not based on an extensive scientific understanding. This shows a potential to address misconceptions developed by students as they design and make in technology.

The focus group interview data gathered from the students indicates their understanding of the concept of centre of gravity and its significance to the luge design. The students were again asked why the body pans are lowered to the ground, in response students made both direct and indirect references to centre of gravity and aerodynamics. For example, HM, TJ and BA showed a clear understanding of the reason behind lowering the body pan and frames more towards the ground as is obvious from the exchange below:

TJ: More speed.

HM: So you can't slide off and easier to steer.

BA: Less bouncy.

HM: More aerodynamic.

This excerpt from the focus group interview indicates the student's ability to recall ideas from science while designing and making their body pan-frame combination. Students were able to recall the idea of centre of gravity and aerodynamics which was discussed in the design room in Stage 1. An excerpt from BA's portfolio (see Figure 6.2) also indicates a similar understanding developed by the student after constructing and testing the luge.

insure it would stay secure and will not undo. The purpose for my chassey not going through the whole body pan was to make it flexible and bouncy; so when I am riding over a bumps, stone etc. I would not feel any resistant. This gave it a more comfortable ride because it felt soft on my body.

Figure 6.2. BA's frame construction and alignment with the body pan discussion (taken from BA's technology portfolio.

It could be derived from Figure 6.2 that the design decision the student took in the workshop resulted in a structurally stable luge. The theoretical understanding of science may not have been present but its implicit application was present in BA's technology portfolio. However, the student may have not realised it and was not able to identify it during the interview. BA mentioned the reason for his frame not going through the whole body pan was to make the whole riding experience 'less bouncy'(BA, Focus Group Interview) by designing the luge to handle bouncy conditions which seems consistent with the data from the portfolio. This is a good example of where student might not have realised his design was aligned with science principles.

LG, EM and MY also highlighted the rationale for lowering the body pans to the ground during the interviews. The reasons provided included speed and stability for the luge. LG also noted the concept of centre of mass being lowered toward the ground providing a stable ride with fewer air drags (as interpreted by his use of the term 'aerodynamic resistance' as he understood the term). This indicates that the student interpreted lowering of the centre of mass as a way to provide less aerodynamic resistance:

> The centre of mass, so being able to be lowered to the ground is more stable, and since you are low, you are causing less aerodynamic resistance so you can go faster. (LG, Focus Group Interview, Stage 3)

This indicates that the students may interpret their understanding of the science in a way which might not have the same meaning in the context of science. The interpretation made by the students may not be well aligned with scientific concepts. Also, EM and MY agreed with LG's theory on lowering of the body pan more to the ground for speed and stability but did not comment on the aerodynamics of the luge. LG and MY further commented on the element of trial and error in technology, where the balance between theory and practice is achieved through a process of continuous trial and error to implement theory into practice. They were referring to the optimum clearance achieved between the body pan and ground by trial and error method. The trial and error or prediction involved the placement of the body pan on the frames and the correct placement of the wheels on these frames. TG, MQ and JC referred to the concept of centre of gravity which helped in achieving optimal speed and stability without overturning the luge. NT, JS and JV agreed that such an arrangement has its effects on reducing the speed wobbles and aerodynamics.

The body pan and frame construction was a phase where students gained considerable thinking and practical abilities to solve problems, as identified by the students in the student questionnaires from Stage 2. The student questionnaire data indicates that these skills were developed while laminating the body pan and determining the elevation required for the frames to accommodate the body pans. The shape and alignment of the pan with the frame was also inspected by the students for aerodynamics and stability. The weight distribution factor and the determination of the weaker sections of the pan-frame combination, were also conducted at this stage. Students also indicated that they referred back to material research from Stage 1 while manipulating materials in the workshop in order to move forward with their production. The practical skill of applying mathematics in the form of calculations and measurements was also considered to be essential by the students. This stage also required the students to foresee their product in advance (in the mind) to solve problems as they developed their luge.

During his interview, the teacher also confirmed the use of mathematics by the students in the form of measurements and symmetry during the chassis formation. The properties of materials related to manipulation and processing utilised by the students during construction were also recalled by the teacher. The teacher confirmed that the chemical properties like corrosion and environmental resistance of materials and ways to prevent them were discussed with students during this phase. The teacher mentioned that students may relate and see the relationship between the theoretical and abstract science concepts with their applications in technology.

The teacher also advocated that during the stage of assembling the body pans on to the steel frames, students were capable of identifying the weaker sections of their body pan-frame combination. The students were familiar with the idea of force applied to the body pan and frame. The teacher indicated that students initially did not identify the region between the rear and front wheels as the most important section to be recognised as it provided the strength to their luge. This implies that students exhibit various levels of expertise and the presence of an expert (teacher) is necessary in a technology classroom to facilitate negotiations with the constraints. The teacher introduced this to students during the construction phases which helped them to critically think and problem-solve around the weak sections of the luge. An expert in the classroom who has the ability to point out the design aspects of a structure and practices through functional modelling and scaffolding would be advantageous for the students.

6.1.8 Weight Distribution

The weight distribution rule of 60:40 was drawn from the Internet by the teacher and presented to the students in the design room in Stage 2. The rationale for introducing the procedure was to determine the correct positioning of the trucks and wheels along the frames to achieve a smooth and controlled navigation of the luge. The students were asked in the interview to explicitly identify any scientific and mathematical principles applied at this stage of the project. JS and NT identified science in the form of forces or weight being applied to the luges, and the distribution of the weight through the trucks plates to the wheels. Application of mathematics in the form of calculating the percentage of the total weight was identified by the students at this stage. The students mentioned that they opted for the 60:40 weight distribution because they were instructed to do so by the teacher. JS, JV and NT made it clear that they did not know the rationale for the weight distribution until they finally tested their luges. JS did identify the importance of weight distribution during the interviews, noting that the front wheels needed to carry the maximum weight for better speed and stability. JS also indicated he could have made his luge stronger by placing more braces wherever bending was taking place, or by adding reinforcement in the middle. The students were satisfied with their weight distributions after testing their luges, as indicated during the interviews and from the portfolios (see Figure 6.3). JS's evaluation report indicated that he thought his wheels evenly distributed the weight of the pilot to the ground, covered more distance and achieved higher speeds. JS was able to bring his knowledge from the distribution of weight using the longboard wheels (Stage 1- momentum testing conclusion) towards the end of Term 4 while writing his evaluation reports. The students followed the teacher's instruction to use the weight distribution ratio of 60:40 in the workshop. The instructions were provided in the design room but there is evidence from Stage 2 that many students did not follow the procedure and did not understand its rationale. It could be said that the students understood the rationale (reason) for weight distribution better after testing their luges as they mentioned this during the focus group interviews and were able to comment on further improvements on their luges.

> The wheels that I eventually used after extensive testing were 69mm - 75mm long board wheels, as they covered a larger distance and spread the weight ratio more evenly.

> The framework was strong - able to withstand my weight and speed especially when I crashed. When I did crash the luge, it withstood any fractures or bending.
> Achieved high speeds

> The luge has to be able to withstand the weight of the pilot - The luge carried my weight effectively without any stress on the components and in fact, proved to be very fast.

Figure 6.3 JS's evaluation of his framework, indicating his satisfaction with his wheels, speed, frames and the weight distribution.

HM and BA indicated that they used the 60:40 weight distribution as instructed by the teacher in the design room. TJ used a weight distribution ratio of 50:50 instead and indicated that his luge worked perfectly; he came fourth on race day. BA, HM and TJ indicated that they understood the rationale for the weight distribution after testing their luges. HM, TJ, BA and SS were all satisfied with the weight distribution of their luges, as expressed during the focus group interviews. TJ indicated in his portfolio that he designed his luge to carry a total weight of 120kg and was successful in constructing one that could fulfil its intended purpose, as is evident in Figure 6.4. There is evidence available from this class to indicate that ignoring the teachers suggested rule of 60:40 weight distribution still resulted in a product which fulfilled its intended design attributes. This again supports the element of trial and error and the risk which comes in designing and construction.

Weight restriction- maximum weight restriction

The weight restriction for my luge is 120kg so my Dad can ride it. This also means that anybody under the weight can ride it. The weight restriction helped me on the day because it did not break.

Evaluation

Wheels- The luge will need wheels to move downs the track.

At the start of the day I was using skateboard wheels , these were slow as they had old bearings in them. I changed the wheels to longboard wheels so my luge was faster, this helped because I was one of the fastest luges as I made the top ten and went on to come fourth place.

Figure 6.4 TJ's evaluation report on his weight distribution/restriction and wheel selection.

MY mentioned that he completely ignored his weight distribution and his luge still performed fine on race day:

> I didn't actually use my weight distribution because it showed it was too far forward, and it just would have been really weak in the middle. That's why I actually moved my trucks back to make it stronger, so

it won’t snap in the middle. So I completely ignored the weight distribution, but it still turned out to be fine. (MY, Focus Group Interview, Stage 3)

MY indicated at the conclusion of his evaluation report that he was happy with the functioning of his luge. However, if given the chance he would have brought his rear trucks forward a little to add extra stability to the luge. This conclusion was derived after he tested the luge. The students clearly developed a better understanding of the luge’s functioning while working and testing it. Evidence from MY’s portfolio is displayed below in Figure 6.5, showing that his luge performed well during the race.

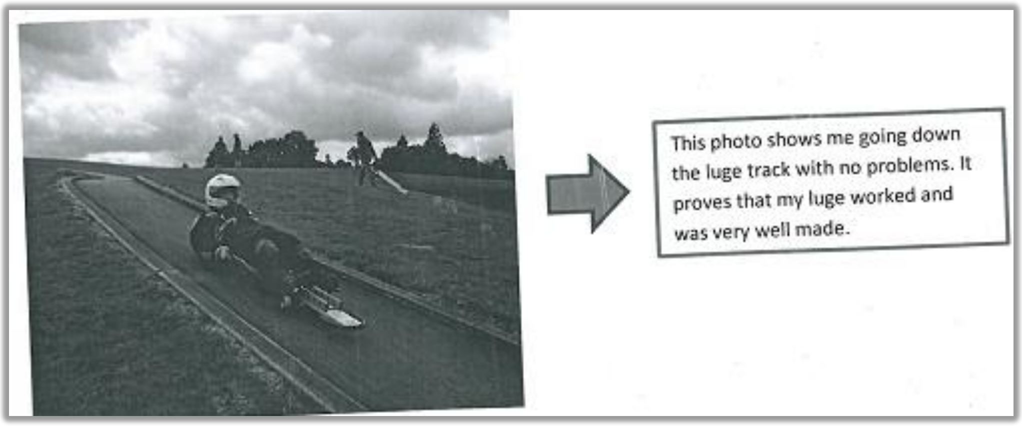


Figure 6.5 MY’s evaluation of his luge indicating desired functionality of his luge.

The students also commented on the structural stability of luges belonging to other students, when making points during the interviews. For example, LG commented on EM’s luge and implied that the weight distribution was dependant on the structure of the frame which indicates the ability of this student to critique other designs. LG pointed out that his frame had more ride height (ground clearance), so he faced the challenge of fine-tuning the steering and stability by placing the wheels in the appropriate positions. LG and EM also mentioned that they understood the idea of weight distribution when it was initially discussed in the classroom and performed the procedures themselves. Figure 6.6 shows evidence from their evaluation reports that their luges performed well during the race. This indicates LG’s ability to make critical judgements and comments on the structural stability of the luge based upon his experience and observation. Students were successful in developing a functional product in the workshop by appropriating tool related and manipulative techniques. They further demonstrated an extended understanding of their product by performing trail tests and by drawing conclusions based upon them with suggestions for improvements.

> Steering: on the race day my trucks held well, they were facing the right way, held correctly with no bolts coming undone, and only needed minor tune ups to suit the tracks steering and speed requirements, my stake holder agreed that the trucks were at the perfect tension to handle the tracks turns

> **DID EVERYTHING GO WELL** On the race Day my luge was going alright but I did have to tighten up the trucks a couple of times to make the steering better. Also I had to keep adjusting the handgrip position because of the way the pilot sits on the luge.

Figure 6.6. Evidence from LG's and EM's portfolios regarding the steering and performance of their luges.

The luge testing on race day provided the students with an opportunity to learn by putting the theory into practice. For example, BA understood the weight distribution concept better after testing his luge on the track, when he realised the distribution of his weight on the luge was more in the middle than at the front which in turn affected the speed. This was evident from his evaluation report, shown in Figure 6.7. Technology provided students with practical opportunities to interact with their design to identify constraints and flaws in their own designs.

> Speed: The speed of my luge was not very fast. But the intention of my luge design was to get the best designed luge. Besides from that, I believe my luge did not go as fast as I had expected because it was mostly heavier in the middle of the luge, instead of at the front of it. If most of the weight was at the front of the luge, it would than carry more and more momentum going down the track.

Figure 6.7 BA's evaluation of his speed based on his weight distribution.

It was also observed in the workshop that many students followed what others were doing in terms of weight distribution without putting much thought into the rationale behind their actions. For example, JC said he did not have any idea what was going on in the classroom when weight distribution was being discussed. MQ also said that the procedure of placing the maximum weight on the front wheels was straightforward for him. TG added that he understood the concept of weight distribution and knew there was no point adding weight to the back of the luge. The only scientific principle identified by the students during this stage was the distribution of weight along the length of the luge. The importance of mathematics, in the form of calculating percentages, was identified by the students. MQ and TG mentioned that they grasped the idea of weight distribution when it was initially discussed in the classroom. MQ, TG and JC were satisfied with the final weight distribution and overall structural integrity of their luges after testing. Evidence from the evaluation reports also confirmed their (MQ, TG, JC) satisfaction with their chosen weight distributions. This indicates that some students may have not understood the theory and rationale behind the weight distribution while it was discussed in the design room, but were able to follow the procedures to make the luge. After testing the final product on the race day, the students developed a better understanding of the structural integrity and weight distribution of the luge.

The teacher’s comments on the weight distribution process and the application of science during this phase were recorded during the final interview. The teacher mentioned that the students understood the distribution of weight across their luges, evidenced by their identification of the bending regions on their frames and the appropriate provisions for support. The teacher mentioned that students initially considered the materials they would be using to construct their luges, and the weights on them, to identify the weaker sections and take appropriate measures to support them. However, the data from the student focus interviews suggest that many students may not have understood the significance of weight distribution until they tested their luges out on race day.

The next section will present findings on the perceptions of the students’ regarding their design and construction experience and the application of science and mathematics in the context of the luge project. This data was collected during the focus group interviews at the end of Stage 3 and is presented as a different section to provide the reader a better understanding of the experience and issues faced by the students in applying science and mathematics (as perceived by them) in general for the luge project.

6.2 Experience of Applying Science and Mathematics to the Luges

The students expressed a range of opinions when asked to share their experience of applying science to their projects. MQ, TG and JC said they made their luges without identifying or applying any scientific principles, as they just followed the procedures they had been taught to make the components and assemble the project. JS found it useful to apply 'science' of weight distribution (adding braces) to improve his luge's performance. JV also considered the weight distribution as 'science' and commented that it was annoying when the trucks were not aligned and positioned properly, as this made the frame bend to an unacceptable degree. NT and TJ mentioned that they had never employed any scientific principles while designing and making their luges. TJ mentioned that the only possible use for science was related to aerodynamics and forces, but even in this context its use was not extensive. It can be seen that students had mixed opinions on whether the science was implicit or explicit in the design context.

HM and SS mentioned that they did not consider scientific knowledge like aerodynamics even while making their nose cones in Stage 2, indicating their interest was in making the product rather than considering the science behind it. Evidence from TJ's portfolio, showing how his nose cone was designed for aerodynamics, is shown in Figures 6.8 and 6.9. TJ designed his nose cone to reduce drag and to increase speed as indicated in his portfolio. It is worth noting that it was TJ's theory that a pointed triangular shape of his nose cone provided less air drag and higher speed for navigation. TJ might have gathered the idea of a pointed triangular nose cone from his design experience, but it is worth noting how the student referred to 'less air drag' idea indirectly referring to aerodynamics. Student used common and everyday terminology to explain his design decision. Term like 'aerodynamics' have been explicitly used by the student but his discussion around his design decisions highlights his understanding of the product.

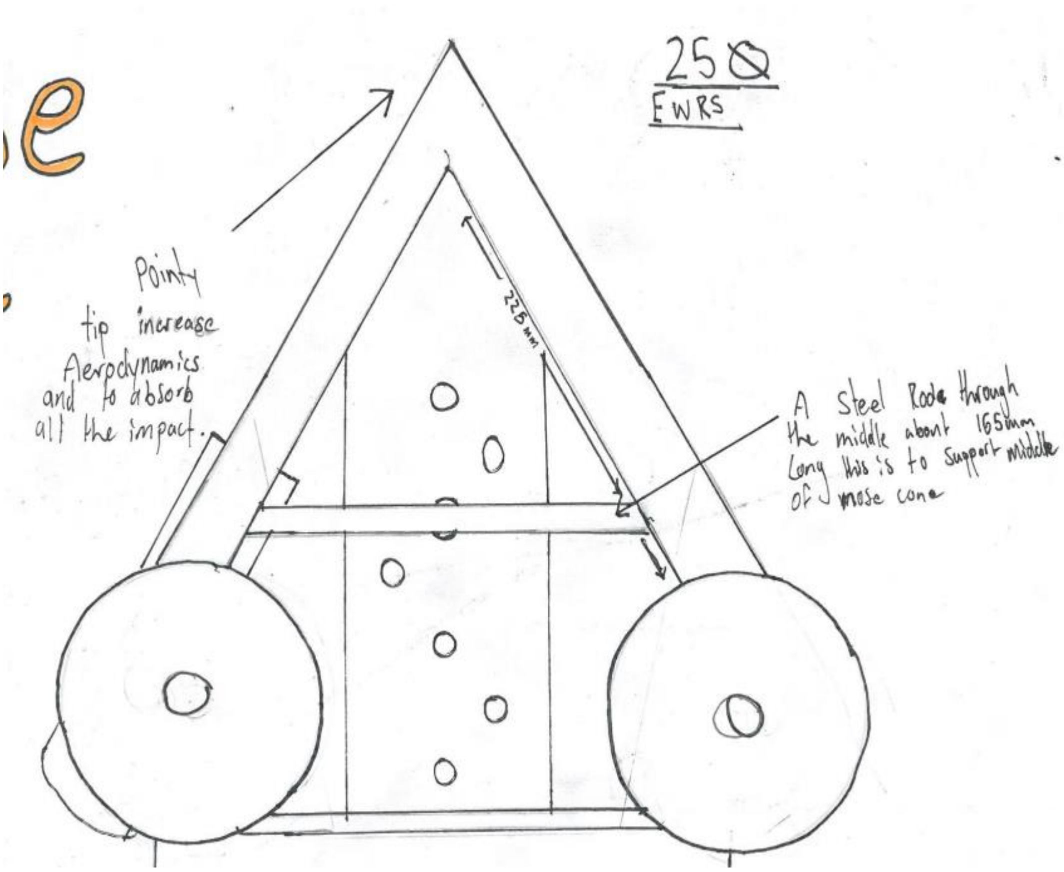


Figure 6.8 TJ's nose cone design indicating the use of a pointed nose to improve the aerodynamics of his luge.

Nose cone- Triangular nose cone for bumper. The nose cone is triangular so that aerodynamics can be increased so my luge will be able to hit top speed going down the luge track. This worked on race day because the bumper protected the front of the luge when it hit the wall. Having a pointy nose cone also helped the luge because it meant that aerodynamics could be increased and the luge went faster.

Figure 6.9 TJ's evaluation of his nose cone.

The teacher indicated that students may sometimes work in a technology classroom without realising that they are applying scientific and mathematical concepts during design and construction tasks. According to the teacher, prior knowledge of science and mathematics plays a significant role in technology, and it adds to the academic focus of this subject (technology). The students not only made a working product, but also applied knowledge from other domains to develop a practical understanding of the application of concepts, as noted by the teacher:

> I think they should also know about this knowledge, otherwise they cannot understand why materials behave differently under various loading conditions and what can be done to make them stable by making some decisions. If they don’t know some of the things from science, they won’t be able to develop an inquiring mind. Instead of being told that this material is suitable for your project, we should give students a chance to experiment with things so they can decide by themselves. (Teacher, Final Interview, Term 4)

This comment shows that the teacher considered experimentation and decision making to be important in technology. This prompted the teacher to initiate integration of information to deepen the students’ understanding through the application of the information to materials, so that the luges would function in the intended way.

Some students were capable of explaining the problems or issues encountered in the field using scientific terms and concepts. For example, EM and TG mentioned instances of making minor changes to their luges after testing. During the focus group interview, EM noted:

> I think when we went to test our luges down the hill my truck plates came off, and I think it was because the tensile strength was not enough to handle the stress produced by the weight. (EM, Focus Group Interview, Stage 3)

EM had to replace his truck plates and bolt them to his frame again on race day. He provided an explanation of this on the basis of the theory of tensile strength and that stress is produced on the truck plates while speeding. This indicates the use of scientific concepts in the context of technology. TG mentioned that his frame was bent too far after he positioned his trucks and tested them, but identified no scientific reason. On further questioning, TG mentioned that the centre of gravity was behind this issue, as evident from the interview excerpt below:

TG: Not because of any scientific reason but it was just kind of bent too far, and I was kind of ‘nah’.

R: OK, what made you think it was bent too far?

TG: Oh, because I knew that my trucks would not be, like, even with a few inches, and it will not keep it off the ground.

R: So do you think it has a scientific reason then?

TG: Maybe a bit to do with centre of gravity?

This excerpt indicates that the student may not be aware of his thought processes in regards to science. TG identified this issue while racing at the park as he could not get enough control of his steering to make it through some of the curves, as shown in Figure 6.10. TG identified the issue of lowering his frame more to the ground (which effected his navigation) as evident from the focus group interview and portfolio excerpt and on further questioning referred to the scientific concept of centre of gravity. This indicates again that student may not be aware of their thought process in terms of the underlying scientific explanations.

Steering

My luge was able to navigate the track at Minogue but when I went to fast I couldn't get enough leverage to make some of the corner, so if I could change anything I would make my luge not so low to the ground

Figure 6.10. TG’s evaluation of his steering.

The students mentioned during the focus group interviews that they were happy with the overall structural integrity of their luges. The various stages of designing, constructing and testing provided the students with a practical understanding of the functions of the luge components. A few examples of the conclusions derived by different students are provided in Figures 6.11, 6.12, 6.13, and 6.14.

My gravity racer was safe as I did not get hurt while riding it and it had a good riding position because it was comfortable riding position.

My luge was able to support my weight as I was able to complete my runs

Conclusion

In conclusion my luge performed well on race day and meet all of the specifications and attributes required and it was also able to navigate the luge track at Minogue park with ease and without breaking witch showed me I made it to a good standard

Figure 6.11 TG's evaluation and conclusion.

My gravity racer was safe as I did not get hurt while riding it and it had an effective riding position because it was comfortable and easy to ride while lying down on it.

My luge was able to easily navigate the luge track as I could take all the corners while racing,

My luge was required to hold my weight of at least 65kgs and it could easily do this without the frame bending too much as can be seen in the picture below.

Conclusion:

In conclusion to my luge evaluation I believe that my luge was very successful at race day as it negotiated down the track at Minogue park and meet the specifications and required attributes. My luge did not break at the end of race day which provided to me it was built to a good standard and everything throughout race day went well with my luge.

Figure 6.12 MQ's evaluation and conclusion.

Conclusion:

The luge I made proved to be durable, fast and above all, a lot of fun. I managed to reach good speeds in the last run. I found it easy to manoeuvre after fine-tuning and through a number of test runs. It withstood some impressive crashes and retained its structure and core components.

Figure 6.13 JS's evaluation and conclusion.

Conclusion: In conclusion I am very proud of the way my luge has turned out. I have learnt new skills of how to use many materials from shaping plywood, linishing aluminium to upholstery. When tested it felt very balanced and turned easily. Although my luge wasn't the fastest on race day it was fast enough for me. This was a fun project to do and since race day I have used it many times with my family just to have fun.

Figure 6.14 BA's evaluation and conclusion.

The use of basic mathematics was explicit within the context of luge design as already discussed in Stage 1 and Stage 2. On asking for comment on their experience of applying mathematics to their project, students again expressed a range of opinions during the focus group interviews. MY and EM commented that the application of mathematics helped them during the design and construction phases. MY and EM also mentioned that mathematics was their weakest subject and its application in technology makes the subject relevant. MY commented:

> It is actually quite fun to because you are learning and doing something, but sitting in the maths classroom can get boring at times. (MY, Focus Group Interview. Stage 3)

LG further commented that he enjoys technology because it has a practical component where the application of theory comes alive. This indicates that the practical aspect of technology naturally creates a platform for mathematical calculations. EM also commented:

> I think people like us at our age, especially boys, find it easier to do practical stuff. (EM, Focus Group Interview, Stage 3)

TJ started by commenting on the significance of getting the right measurements during designing and making to be precise with the calculations (HM and BA agreed with TJ). TJ also noted that the maths knowledge required in the luge context was really basic. For MQ and TG, the calculations were straightforward and MQ further mentioned that he could have done these calculations even in Year 9. NT and JS found the application of mathematics in technology ‘boring’, especially when they had to construct the truck plates with appropriate measurements. The data collected from focus group interviews highlights the varying degree of expertise exhibited by the students while designing and making. The attitude of the students towards mathematics and its application differed from one focus group to the next.

The application of mathematics (basic calculations) was extensive as observed by the researcher during classroom observations, which was also confirmed by the teacher and students during the interviews. The application of mathematical concepts in technology can take any form during design and construction phases. For example, MQ indicated he had used the mathematical concept of the circumference of a circle to determine the length of his head rest:

> A little bit from the head rest as I dealt with the radius times pi, and I got how wide and long the aluminium sheet had to be. I had to put my head rest into 30 cm as the base, so I took radius times pi, and then I got the circumference and halved that, and it gave me how long the metal would be. (MQ, focus group interview, Term 4)

This example shows the extended application of mathematical concepts within the context of luge design. MQ drew on his understanding of mathematics, as seen in Figure 6.15, to explain what he meant during the interview. Figure 6.16 shows the final head rest designed by MQ.

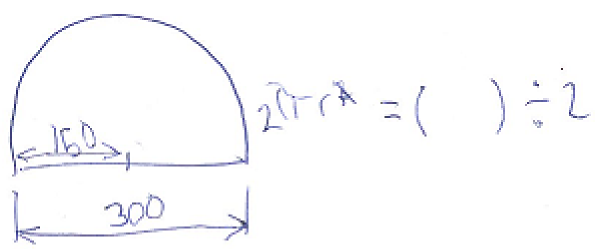


Figure 6.15 MQ's calculations during the interview drawn to explain his understanding of a mathematical principle.

Figure 6.16 MQ’s final headrest.

This is good example of the application of mathematics in the context of the luge. Technology provides situations and contexts which requires problems to be solved as they arise, and during this process it may be necessary to recall information from science and mathematics to solve them. The information recalled may or may not be identified by the user as science or mathematics, but it can still be applied to solve the problem. The next section will present the perceptions and suggestions provided by the students regarding the integration of science and mathematics with technology, and their thoughts on collaborating with science and maths teachers in technology classrooms.

6.3 Student and Teacher Perceptions of Integration and Suggestions

During the focus group interviews, a majority of the students agreed that they had recalled science and maths knowledge learned in previous years while designing and making their luges. The application of science was seen in the use of body actuated steering, aerodynamics, momentum, the streamlined shapes of the luges and the positioning of weight to achieve the desired speed. Ensuring the structural integrity of the luge was considered to be an application of science in technology by the majority of students. The use of applied mathematics in the context of the luges took the form of basic measurements and geometry. There was evidence from Stages 1 and 2, student questionnaires, informal conversations, teacher interviews and the focus group interviews that the information from tension and compression, forces, and motion was recalled in the context of luge design. The teacher identified this as essential knowledge required for problem solving in the context of the luge design.

The teacher also indicated during the final interview that it is difficult to articulate and identify fundamental knowledge in technology without a context, as the context defines the relevance of information. The knowledge is co-constructed as the student starts to interact with the materials within a problem-solving context. Acquiring new knowledge in technology to solve a problem was identified by the teacher as an essential factor. Information on materials and their properties should be provided just in time, so the students can apply their knowledge when they need it. This will help them to evaluate the functionalities of the product (since the development of the luge was the aim for the students) with respect to the properties and processing of the materials. Appropriate and essential science knowledge should also be provided just in time, as indicated by the teacher.

CHAPTER 7 DISCUSSION

7.0 Introduction

This section of the thesis will discuss the common themes that have developed as a result of the chronological presentation of the data in Chapters 4-6. The intent of the structure of this chapter is to take the reader through the goals and interests of the teacher and the students when they come into the technology classroom and the nature of the knowledge they construct. The first two sections will describe the nature of knowledge (predominantly procedural) that the teacher seeks to provide while the students are in a technological design context. The remaining sections will discuss how the nature of technology is conducive to the integration of science, mathematics and technology in a technological design context by examining the practices of the teacher and his students from Term 1 till Term 4.

The discussion is framed in a social constructivist and socio-cultural perspective, highlighting the social nature of practice and knowledge development within the classroom community. The attitudes of the teacher and the students towards integration will also be discussed, and insights into ways of maximising learning opportunities to facilitate an integrative learning environment in technology are further explored.

The data presented from Stages 1 to 3 indicate that the goals and intention of the teacher in the technology classroom was to facilitate the development of a functional product and the use of psychological tools which would lead, knowingly or unknowingly, to the integration of science, mathematics and technology. Another goal of the teacher was to purposefully integrate information from science and mathematics into the luge project so the students could see the relevance of these subjects in technology. After the design phase, the focus shifted more to the development of the product with little focus on science and mathematics. The construction phase was observed to be a plethora of demonstrations, negotiations and appropriation of material manipulation techniques, operational principles and structural knowledge in the workshop with a clear focus on the development of a functional and aesthetically pleasing product. This led to the creation of shared knowledge in the classroom community.

The intent which the students came into the classroom with was the creation of a functional product. The students were curious and excited to work and manipulate materials in the workshop. During Stages 1 and 2, the students consciously conceived and produced various components of the luge in response to their need or desire. Their needs and desires were also influenced by the existing luge models, design brief, materials, resources, tool related practices and techniques, the teacher and stakeholders. The luge design and construction, therefore, was an activity which entailed human (teacher, students and stakeholders) needs and desires.

The findings presented in Chapters 4, 5 and 6 illustrate that knowledge from science and mathematics was recalled purposefully and also integrated naturally in the luge context. The later sections in Chapter 7 will discuss the knowledge constructed by the actors though their interaction within the design environment. An analysis of this knowledge will help explain the integration of science, mathematics and technology in a technological design context and the approaches which assisted or hindered this integration. It is the procedural knowledge of technology which provided opportunities to develop technological knowledge and the application of science, mathematics and technology which will be highlighted in the later sections.

In the following sections, the evidence of the identification (by the teacher and students) and application of science and mathematics in the context of luge design is discussed, and the circumstances which created a platform for such integration is also discussed. This is followed by the themes developed as a result of the analysis of the data collected throughout the various stages which will enable the researcher to answer the main research question in Chapter 8.

Section 1- Co-Construction of Knowledge

7.1 Co-Constructed Knowledge facilitated by the Teacher

Technological knowledge cannot be a defined body of knowledge in technology that all students are expected to learn in order to become technologically literate. Rather, knowledge acquires form based on purposes in specific human activities, and it is interdisciplinary in its use (Herschbach, 1995). The purpose and intention of the teacher in this research was to facilitate students in developing a working product, and this reflects the nature and the kind of knowledge which exists in technology. The teacher's aim was to develop and foster technological capability by encouraging technology-based approaches, that is, equipping students with knowledge of relevant effective technological tools and practices both prior to and while making the product. The subsequent sections will highlight the initiatives taken by the teacher in terms of active discussions and demonstrations that facilitated the appropriation of relevant procedural knowledge and skills to develop a functional product.

7.1.1 Knowledge generated through Discussions and Demonstrations

There is now a considerable body of research that shows that deep and lasting learning is fostered when students actively engage with concepts and construct their own understanding of them (Blank, 2000; Zirbel, 2006). Discussion, debate, questioning and explaining are some of the activities that have been shown to support active learning and the construction of meaning in the classroom (Cohen, 1994; Laurillard, 1993; Matthews, 1996; Springer, Stanne & Donovan, 1999). The data from this study has already indicated the significance of such discussions and demonstrations which created an environment where learning was active rather than passive. The following sections will highlight the information deemed significant and provided by the teacher and appropriated as usable knowledge by the students through discussions, demonstrations and scaffolding which led to the design and construction of a functional product.

Through presentation and discussion, the teacher helped students to appropriate technological applications with a perspective on technological knowledge. He did not use technology as a means to teach science and maths content, even though this may have happened unintentionally. Any approach to presenting science content in technology with an aim to teach and learn science has been criticised, as such an approach tends to portray technology simply as a means to teach science (e.g. Boon, 2006; de Vries, 1996; Gardner, 1994; Layton, 1991). The teacher did not undermine technology and maintained its epistemological position to integrate science and mathematics when students worked in a technological design context. The teacher identified the close relationships that exist among science, mathematics and technology and wanted to represent this in an integrative learning environment (Barlex & Pitt, 2000; Bencze, 2001; Hadjilouca, Constantinou, & Papadouris, 2011; Lewis, Barlex, & Chapman, 2007; Petrina, 1998; Sidawi, 2009). The teacher facilitated the design context with a focus on developing the functional product by providing and recalling student's prior knowledge on materials and manipulative techniques through discussions and demonstrations. The teacher advocated the view of technology as multi-disciplinary and believed in drawing on a range of knowledge from various domains (Petrina, 1998). The idea underpinning the teacher's belief was that the domain of technology constitutes meaningful and motivating contexts for learning into which knowledge from science and mathematics can be integrated (Bungum, 2004).

The discussions and demonstrations in this classroom were predominantly intended to develop an understanding of the luge functioning, and knowing how to use certain tools and materials to make the components work, which is a more pragmatic approach to viewing technology. The teacher assisted the students through discussions, negotiations and demonstrations (psychological tools) to achieve the desired results. The guidance provided by the teacher was visual, auditory and kinaesthetic, which highlights the teacher's know-how in the particular situation. The functions of the various components and their assembly were discussed by referring to pictures from the Internet of constructed luges in order to facilitate student initiated design decisions. The emphasis on acquiring a better understanding of the product seemed to be prominent in such a design environment. The discussions initiated by the teacher around the constructed product were directed towards understanding the structural assembly (engineering theory) and the strength of materials (technological theory).

The next section will highlight the significance of learning about properties of the materials and manipulative techniques which contributed to the development of knowledge specific to the design context.

7.1.2 Knowledge Constructed with a Focus on Materials, Manipulative Techniques and Tool Related Practices

The luge project consisted of a variety of components that were to be constructed using the appropriate materials to achieve the desired design specifications. The teacher introduced the students to the materials available and the various manipulative techniques which could be utilised to develop the product. A study by Esjeholm and Bungum (2013) comments that this type of knowledge (related to devices and technological knowledge) is not possessed by all students, which may obstruct their progress in technology. The teacher had realised this through his practice and experience over the years with the luge design, and focused on providing this aspect of technological knowledge. For example, the tacit knowledge of lamination was discussed and demonstrated with the intent of creating the curved body pans for body actuated steering and to achieve the desired strength during manoeuvring.

The luges created by the majority of the students suggests that they reasoned in terms of the best possible materials and the most appropriate manipulative techniques within the limitations of the design context. The tacit know-how and know-that knowledge was seen to prevail over science or maths content in this technology classroom during the design and construction stages. One such example is where the use of tacit knowledge related to tightening the trucks was used to solve the problems of the steering mechanism and speed wobbles. This information was provided by the teacher to the students verbally in Stage 1 during designing, and it was recalled by the teacher again when needed later on the race day. Testing the luges provided a practical context for the students to address problems that arose, and the teacher played a significant role by providing them with this practical context. The tacit knowledge related to operational mechanisms was utilised to cope with practical problems (Bungum, 2006). The actions of the teacher, to a large extent, resemble what constitutes the core of technological activity as dynamic and situated, where knowledge, tools and procedures are chosen in pragmatic ways to reach a desired outcome (Ropohl, 1997). Various psychological tools were utilised in this classroom within the design context to assist students to design and construct their luge.

The nature and process of technology was clearly visible in this classroom as the activity was to some extent flexible and the students had to decide on the designs and materials to be employed. The teacher provided a context for the students to take part in a technological activity (luge design and construction) which searched for usable solutions (assisted by the teacher) that are optimal in terms of labour, cost (in a broader sense) and results. The resulting product can be understood as an assemblage that emerged from situated activity, negotiations and interactions of the designer with the various resources and tools available in the environment (Roth, 1995), since the knowledge generated depends upon such interactions. The knowledge students develop during such interactions with the community, tools, resources and materials is directed towards understanding the physical nature of the product. It was observed that information from science and mathematics was not purposefully recalled to explain the physical phenomenon to indicate its relevance within the context.

The next section will feature the intentions of the students and will highlight the nature of the knowledge they seek to appropriate while designing and constructing.

7.2 Co-Constructed Knowledge Facilitated by the Students

Students in the classroom constructed a shared version of knowledge through their interaction with the various actors (teacher, fellow students and stakeholders) and resources, tools and materials during the design process. The students' understanding and knowledge was shared and goal-oriented which allowed the researcher to focus on this knowledge to investigate the integration of science, mathematics and technology. The final luge product cannot be said to be shared because the students began with individual ideas and produced customised luges where procedures of making the individualised components were established through discussions, demonstrations and appropriation (of the techniques) which resulted in the shared co-constructed knowledge. Students were able to generate a shared version of knowledge through their interactions and participation in investigations to make evidence based claims, or by following the teacher's prescribed instructions and practices, or by consulting fellow students. Locations within the design environment (including classroom and workshop) where students gathered were ideal sites for such learning to occur. Students were also seen to congregate at various knowledge dispersion centres such as the workbenches, around machines and in the design room. These were the sites where they could discuss each other's work and ideas.

The next section will discuss the integrated knowledge that was co-constructed and shared by the students through participation in discussions and demonstrations through mediation with the use of psychological tools.

7.2.1 Through Participation

The nature of information and knowledge acquired by the students in the technology classroom was guided by the focus on the construction of the luge. Thus it can be said that the intent or purpose of an activity defines the nature of knowledge constructed within the context. For example, the choice of wheel size, selection of appropriate construction practices, reference to constructed products to achieve a functional product are just a few examples which indicate the nature of knowledge acquired. The tool-related practices and material manipulative techniques appeared to be adopted rapidly by the students as it was a significant part of the construction process for successful completion of their luge. The interaction among the members of a classroom community, materials, resources and the tools transformed the physical (student's work places around the workshop) and social settings (high population of student accumulation during demonstrations) of students' work and consequently, the nature of knowledge acquired and developed by the students. In a classroom of technological activity, "despite the differences among individual interpretations and constructions, participants do communicate, negotiate, and compromise; in short, they 'design'" (Buccairelli, 1994, p. 81). The mediating role of language (talk amongst the students and teacher) as a part of a technological activity, has been highlighted in a study of architects (Medway, 1994; 1996), who not only draw, but talk, write and gesture in participating with others to accomplish their task of construction, similar to the students from this class. The various episodes from the classroom showed that the students were able to adjust their actions and follow procedures to develop knowledge and skills.

The gravitation of the students towards common locations where various procedures like cutting, sawing, welding etc. were carried out facilitated interaction among the students and the design environment. It can be said that the demonstration of tool-related practices and procedures to manipulate materials enhanced the interaction (increased student interactions). The grouping of students during the momentum testing, material testing, process testing, lamination of plywood, and discussions around constructed luges are just a few examples of the opportunities in the design room which led to the exchange of ideas, peer teaching of tool-related practices, support during construction, and peer critiquing of designs.

The shared version of contextual knowledge was developed and internalised by the students through observations, experimentations, investigations, copying or learning from verbal instructions provided by the teacher and fellow students. These practices, which are directed towards creating an artefact through instructions and demonstrations, were embodied by the students through their actions. A set of actions becomes meaningful practice when carried out within a social and cultural context as the intent of the actors is to match their actions through practice and trial and error (Roth, 1996). In this way, the practice or actions that result from verbal instructions, observations, written instructions, drawings and briefs, take form through their use within the context. Students, to a large extent, rely on the procedures introduced by the teacher to move forward, and in this design process, embody the practice which in turn defines the nature of knowledge co-constructed by the students socially.

The tool-related practices and the manipulative techniques demonstrated by the teacher in the workshop did not necessarily automatically transfer to the students through observation. To become a member of a classroom community and engage with the practices of that community, a member has to be familiar with the resources and embody its practices (Roth, 1996). Students in this classroom had to find ways, through their experience and curiosity, to appropriate various manipulative techniques. This happened not by only observing the practices of the teacher but through repeated trials. For example, the dip of the frames towards the ground so as to accommodate the body pans was not an invention, but a standard operational principle developed by the teacher and the students in Stage 2. Students were focused on assembling the body pans to the frames by establishing the appropriate clearance from the ground through a trial and error method. The vicarious experience of investigating and constructing the components of the luge through trial and error became embodied in their own set of knowledge, skills and practices. It is only through the embodiment (repeated use) of tool-related practice and techniques, that its members become integrated into a community.

Having discussed the various mechanisms which led to the creation of shared knowledge among the community, the next section will highlight the transformation from a novice to an experienced member in a community through participation and adaptation of tool-related and intellectual practices.

7.2.2 Through the Adoption of Tool-related and Intellectual Practice

The students can be referred to as newcomers who worked side by side with more competent people (teacher and other students who were competent with workshop procedures) to receive the necessary support in order to become competent themselves. In this way, students became aware of the shared practices and developed common knowledge (what everyone else was doing or how it was done) in the classroom (Barab & Duffy, 1998). The design process involved gaining competence in the effective use of materials, tools and resources which can be described as stages of modelling, scaffolding and fading (Collins, Brown, & Newman, 1989). With the guidance of more competent peers, students could practice on their own, accompanied by the instructions from the teacher or peer (scaffolding). Over time, iterations of this practice resulted in the newcomer becoming accepted in the community, but also occasionally referring to a more competent peer when the nee d arose (fading). An example will be continuous participation of students in the workshop to accept the cultural and social practices theough guidance provided by the teacher. Students requested timely assistance from the teacher during the construction stages of the project when the need arised.

In addition to the resources and tool related practices, design thinking (like curving the body pans to the correct fit, lowering the frames to the ground, fitting the body pans on the frames, adding braces to the frames) had to be carried out as these were integrals part of luge construction. The design and planning phases took nearly 13 weeks before the students started the construction of the product in the workshop. During this time, students became familiar with the functioning and operation of the various luge components and their operational principles. After 13 weeks, but only with considerable and continuing teacher assistance, the students began to construct the luge components. The students could connect the rationale for the shapes of the components with the practices in the workshop, which indicates the adoption of what Roth (1996) called concept-related practice. For example, the rationale for the curved shape of the body pan and lowering the frames to the ground (for lowering centre of gravity to achieve stability) was recognised by the majority of the students in Stage 1, and they responded appropriately when questioned by the researcher in Stage 2 (construction) and during the focus group interviews. Students experiemented with the luge components to achieve the right clearance from the ground for the frame-body pan combination. The adoption of design thinking by the students is largely the result of the focus provided by the teacher in Stage 1. The focus provided to the students by the teacher resulted in students taking control of their product and initiating experiments (trail and error manily) to achive the desired outcome.

There were examples where individual practices did not comply with the instructions provided by the teacher or were modified to serve the interest of the students (such as ignoring the weight distribution rule). Thus, even after a considerable effort was made by the teacher to explain to the students the golden weight distribution rule, there were a few who did not consider the rule and still achieved a working product. Some members of this classroom community did not accept or adopt the concept into their practice, which shows that the adaptation of individual practices was based on trial and error, not solely on the teacher's advice. Thus, even after repeated reference to the weight distribution rule to the whole class and in small group situations, the notion did not become part of all of its members' practice.

The adoption of tool-related and intellectual practices by the students was rapid as it was a requisite for constructing their luges. The students were in control of their learning in practice. Knowledge was distributed, and different students came together in an environment where they interacted with each other to create a common and shared version of knowledge (McDermott & Snyder, 2002; Wenger, 2006). The quality and quantity of knowledge students acquired in this student-centred classroom was authentic with respect to the product, and it was developed while designing and making the luge. This was facilitated when the teacher and students utilised existing knowledge (represented in Internet, constructed luges, tools and materials, and other psychological tools) and know how (techniques) to create new combinations of knowledge and skills. The following sections will focus on the distributed and situated knowledge brought in and applied by the teacher and students, which will lead to a discussion of the interaction of science and mathematics while doing technology.

The next section will highlight and discuss the instances where information from science and mathematics was naturally recalled and aligned with the procedural knowledge of technology.

7.2.3 Interaction of Cross- disciplinary Knowledge in Technology

In the beginning of the project, the teacher mentioned to the researcher that he wanted to integrate information from science and mathematics in the luge context for the students to understand the relevance of science and mathematics in technology and so successfully complete the luge project. An example is the intentional inclusion of tension and compression information to help the students understand the effect of applying weight on laminated plywood and mild steel sections. The teacher wanted the students to identify and choose the best possible material and manipulative techniques for making the luge components (for body pan and wooden frames). The use of scientific terminology during the material testing phase was prominent and assimilated naturally into the discussions around the properties of the materials. This is worthwhile to note since the operational principle of adding fibreglass to plywood and steel sections was explained using information from science to explain the phenomenon observed. The intent of the teacher was to provide students with an opportunity to observe physical phenomenon such as bending of materials, so they could understand the scientific information and apply it to their material selection process. These demonstrations created an opportunity to integrate information about tension and compression from science to strengthen student's theoretical understanding through practice.

There is also evidence of integration which happened unintentionally. The data from Stages 1, 2 and 3 suggests that the science and mathematics were presented in both abstract and contextualised form in this design and technology project. In Stage 1, discussions generated around the effect of the wheel size on the speed of the luge showed considerable potential to consider information from science which students applied in deriving and explaining their conclusions. There is evidence from the portfolios that students understood the explanation for the faster performance of the 100mm diameter wheels over the 50mm diameter wheels. The reasoning behind their claims derived from evidence collected from the field and information from science and mathematics which emerged during the classroom discussions. It was through discussions focused by the teacher around the why aspects of the available data which initiated the consideration of information from science and mathematics. The information from science may have provided an explanation but may not have helped students to build a luge. In technology, structural and mechanical operations are more immediately useful in generating the product than knowing the science behind their operations.

The teacher provided the structural and mechanical operational principles for making the luge in addition to various functional and performance parameters to construct the luges. This makes sense from a pragmatic and technology-oriented point of view, as the science behind the operations of the luge components will not assist the students to make the product. The information from science will assist students to understand theoretically why certain components work in a particular fashion but such knowledge, by itself and without application, has little significance to a student to wants to practically develop a product. The materials were readily available in the workshop and the manipulative techniques were demonstrated by the teacher and appropriated by the students. This resulted in making the product which fulfilled its functional and performance parameters. The timely facilitation provided by the teacher was readily available in the classroom and contributed to the higher quality of the product than would have been the consequence of leaving the students to figure out the process of selecting wheels, materials and manipulative techniques by themselves. This would have been time consuming. A sole focus on the practical ways of developing a product may have diminished an understanding of the underlying science principles governing the functioning of the project. There was a need to study the effect of weight on laminated plywood and steel, for which the information from science was purposefully integrated. Thus understanding the working principles and operations in addition to their structural properties provides an opportunity to integrate information from science and mathematics.

A fundamental goal of science is to generate sensible explanations of the material world (Program for International School Assessment (PISA), 2015). Explanations are devised through empirical testing and enquiry. Results from empirical experiments are reliant on certain well-established scientific concepts with the notion of dependent and independent variables, controlling of certain variables, measurement types, errors and minimizing errors, observation of emerging pattern, making sense of the pattern, and methods of presenting data. During the momentum testing phase, the teacher made the students test the effect of different wheel sets and pilot weights on the speed of the luge. The experimentation can be said to be controlled in the sense that a single pilot conveyed the same luge downhill (three trails) with different wheel sets. However, the width of the wheels was not a constant variable throughout the experiment. The experiment cannot be said to be purely scientific, but provided enough opportunity for the students to undertake scientific enquiry to understand the effect of different wheel sizes on the speed of the luge. The data collected during the trails where logically discussed by the teacher in the classroom using concepts from science and mathematics which assisted the students to make sensible conclusions incorporating science explanations and design decisions. It can be said that the knowledge of the concepts and procedures are scientific enquiry that underpins the collection, analysis and interpretation of scientific data (PISA, 2015). Another example will the systematic testing of laminated plywood and steel bars against loads perpendicular to their longitudinal axis (materials testing phase). Such steps form a body of procedural knowledge which has also been referred ‘concepts of evidence’ in the literature (Gott, Duggan, & Roberts, 2008; Millar, Lubben, Gott, & Duggan, 1995).

Scientific procedural knowledge can be understood as knowledge of standard set of procedures scientists implement to obtain reliable and valid data (PISA, 2015). For example, the teacher systematically laminated the plywood (with and without fibre glass) and demonstrated four set of experiments to understand the behavior of the plywood samples and which sample provided the most strength in tension. Thus, experimental procedural knowledge is essential to undertake scientific enquiry and to engage in critical reflection of the evidence/data to support claims (Gott, Duggan, & Roberts, 2008) in technology. The teacher introduced information regarding tension and compression during before and during the materials testing phases. Gott and Duncun (1995) assert that the understanding of collected evidence requires a 'body of knowledge' which has to be taught explicitly. The information on tension and compression was provided students an opportunity to critically evaluate the results of the experimental observation and tried to make sense of the data both technologically and scientifically through their explanations of design decisions.

The working of product components and their assembly could, in principle, be explained by concepts from science. The teacher did not rely entirely on concepts from science to assist students to design and construct the luge. For example, the discussions and demonstrations about mechanisms represented technological knowledge. Specifically, the second momentum testing phase conducted to study the effect of different pilot weights on the speed of the luge is an example of the application of technological knowledge to decision making about design. A detailed analysis of the student claims in their portfolios indicates that most students concluded that the heavier pilot is faster than the lighter pilot, without a logical reason offered for their claim. The conclusion that a 70mm diameter wheel with a heavier pilot (conclusion) was considered to be adequate by the teacher for the student to proceed and is a form of technological knowledge without an explanation supported with scientific principles. Thus, for the longboard wheels (70mm diameter), neither the teacher nor the students considered it necessary to explain their claims based upon scientific information.

In summary, it can be said that the teacher considered concepts and procedures necessary for designing with a focus on the quality of the product so the students could gain the appropriate knowledge for construction. These practices and procedures, to a large extent, relate to the fundamental aspects of the nature of technological knowledge and practice (Bungum, 2004). The data from this study indicates that technological knowledge was co-constructed by the actions of the teacher and students in this classroom and will be further discussed in the later sections of this chapter. The study has also highlighted evidence of the integration of science, mathematics and technology during discussions and demonstrations.

7.3 Designing- A Collective Activity in a Community

The nature of knowledge evident in this technology classroom is different than what is expected in an inquiry based science or mathematics classroom where much attention is devoted to learning scientific claims and solving well defined problems or mathematical principles. In technology, the intent of the student is usually to develop a product which relies more on tacit or prescriptive knowledge to fulfil the design requirements. As noted by Wheelwright (1966), the meaning of *techne* is what "combines the meanings of an art and a technique, involving both a knowledge of the relevant principles and an ability to achieve the appropriate results" (p. 328). Knowing how to fabricate a component using appropriate materials to achieve its purpose was considered to be sufficient by the students to design and make the luge. As Landies (1980) observed, while the intellectual is at the heart of the technological process, the process itself consists of "the acquisition and application of a corpus of knowledge concerning technique, that is, ways of doing things" (p. 111). The descriptive, prescriptive and tacit knowledge was gained by the students through participating in the community of practice; making continuous references to previously constructed products and to the current state of their artefact to develop an understanding of the assembly. The predictive ability of the teacher and his students (to select appropriate technological procedures) was sufficient to guide actions and to be used as technological knowledge (Norström, 2013). The student's ability to predict and claim in a technology classroom was more prominent than detailed explanations or reasoning behind their actions.

The artefacts which result from designing can be said to be situated and, to a large extent, heterogeneous (Lave & Wenger, 1991). The context of this study can be conceived of as an "authentic" learning environment (Donovan, Bransford, & Pellegrino, 1999) to the extent that the problems which were loosely defined around needs enabled the students to define their goals and frame their problems, but also experience a level of uncertainty in finding solutions. The context allowed students to experience a community in which specific practices and resources were shared, and knowledge was contextualised and socially constructed. The activities which the students undertook to create the final artefact constituted a rich learning environment for working and solving problems in a collaborative manner. The luge design project exhibits some fundamental properties such as students' goals (like for speed and making things) and interests being the starting point for learning and having a focus on practice rather than to accumulate facts (Schank, 1993/1994; Schank et al., 1993/1994; Schön, 1983).

Decisions taken by the students cannot be understood apart from the tools, materials, artefacts, teacher/stakeholder set constraints, design specifications, briefs, or the emerging state of the artefact (McCormick, 2004). Designing in this classroom represented a learning culture and a complex relationship among the psychological, sociological and material aspects within the context; aspects which are considered to be important in the learning of the system and the development of an artefact (Roth, 1996). The artefact designed was evidence of the collaborative planning, constructing and negotiation of the creator and the other actors. During the negotiations between the actors, designs changed and alternative plans emerged resulting in a changing context (Roth, 1996) where individual proposals and problems where transformed into practical solutions to further improve the design.

The initial ideas of the students took form in the emerging designs of the luges. These initial ideas were modified and as they were, other design decisions were constrained and limited. These constraints presented by the context provided an opportunity to interact and negotiate with various actors to develop logical and feasible ideas. The current state of the luge (at a given time) represented the past activity of the students and also provided an opportunity to study affordances and design constraints (Norman, 1988). The affordances constructed by the student, the object and his surroundings enabled the development of a series of possible and feasible trajectories to overcome the constraint. The process of design represents a trajectory and the emerging artefact embodies and enfolds the actual design trajectory, manipulations, decisions, conversations, and so on (Roth, 1996). While making design decisions during various stages of the project, the functionality of the design was evaluated by referring to the current state of the artefact (luge) and by negotiating individual prior knowledge. The final luge is a result of the process through which the students made logical decisions by negotiations, conversations and interactions around the current state of the artefact.

The luges produced by the students can be understood as a collaborative outcome of the various interactions among tools, materials, artefacts, history of activity and design decisions. It can be said in the light of their evaluation reports, the students learned to recognise practical ways to interpret situations with materials, tools, constrictions and other resources. The successful completion of the luges indicates most of the students utilised the flexible approaches provided by the teacher and the design environment in a creative and imaginative manner (Roth, 1996) and framed problems with cooperation and collaboration. Such participation in shared activities is often described as cooperative and collaborative, and these terms may even be used interchangeably in descriptions of social interactions among students (Hennessy & Murphy 1999). Problems did not exist in any absolute sense, but emerged as a result of the interaction of the students with the context and design environment. Most of the students were able to interpret situations and constraints in a flexible manner to ease the problem confronted while designing to afford further design actions. An example will be during the cardboard pattern phase and the selection of the appropriate process to construct their luge. Designers move through iterative phases of thinking and doing, or action and reflection in the widely used terminology of Kimbell (2011) and Schön (1983, 1987). Theory and practice are thus closely interrelated in design, as discussed by, for example, Buchanan (1992), who states that "Designers are exploring concrete integrations of knowledge that will combine theory with practice for new productive purposes" (p. 6) The findings from this study concur with this. The design artefacts allow the reintegration of thinking and acting that some traditional school subject might lack. Designing in this classroom did not solely involve the direct application of ideas from other subjects, rather it was an integral and complex activity that had mental, material, practical and social aspects that apply knowledge in a cultural setting. This has been considered to be a major aspect of learning by many technology educators around the world (Herschbach, 1995; Rossouw, Hacker & De Vries, 2011; Salomon, 1988).

The next section will illustrate the alignment between this study and the conceptual framework.

7.3.1 Alignment with the Framework

The development of the luge had an important social function, as designing is predominantly a collective activity (Suchman & Trigg, 1993). The luge focussed students' attention and communication, and it served to embody the knowledge acquired through discussions, negotiations and interactions with the actors and aspects of the surrounding environment. Providing an opportunity for the students to contrast their own thinking with that of others developed in them a critical appreciation of the different aspects of the problem (Schwartz & Bransford, 1998) that assisted them in learning new and related information (prior knowledge). Students in this classroom interacted with the elements of their surroundings to construct meaning and knowledge. The experience of the teacher in design and make enabled students to initiate technological talks of manipulating and assembling techniques with the students in terms of materials, components and their assemblage helped them to solve problems in the workshop and to construct meaning out of the interactions.

During various stages of the project, students demonstrated an ability to cope with the complexities of the design task where the plan of action changed. This study thus aligns itself to a social-constructivist theory, where learning is seen as an active, continuous process; learners, using prior experience and knowledge, construct and adapt meanings and interpretations of new knowledge obtained by interacting with social and inanimate environments (Bandura, 2001; Crocco 2001; Driver & Bell, 1986; Wittrock, 1974).

Roth (1996) in his study had his students spend most of their time constructing towers, bridges, and huts. He was especially interested in the importance these artefacts played in the social construction of knowledge and made conclusions similar to those discussed in the earlier paragraphs. Roth's study also showed that in some cases the students collectively discovered the engineering knowledge needed to create an acceptable artefact. In this study, the students added braces to the weaker sections of the frame-body pan assembly which they developed or discovered in response to a perceived need rather than following a prescribed solution for achieving stability. This study refers to the knowledge students applied to create the artefact as technological knowledge, acquired through experience and practice. The technological knowledge was established through an element of trial and error which contrasts with engineering knowledge which is predominately contextual with a mainly defined set of steps and procedures with less opportunity for divergent and creative ideas to develop (Williams, 2011). The level of thinking students had to put in through trail and interation was significant in this project.

Students increased their understanding of the design as they progressed and intentionally applied and modified the knowledge to their subsequent work. Towards the end of the term, most students understood their product and the relevant techniques such as strengthening the materials, lamination of plywood, bolting, adding braces, and welding. These techniques are examples of the application of practical knowledge to the creation of an artefact. The literature refers to this kind of knowledge as Device knowledge (Gott, 1988). While designing generally employs knowledge from a range of domains, Device knowledge is a term used in technology education literature (Gott, 1988). It is argued this is as important in technology as it has as its referent the material rather than natural world (Gott, 1988) and reflects the knowledge embedded in successful artefacts – in both symbolic and literal ways. Students developed competent practices related to tools and materials through their active participation in the context. Evidence of these practices and the development of a design culture was observed to be developed in the classroom, where students learned from the teacher and other students many tool-related design practices.

Competence and proficiency of communicating and critiquing design is an important aspect of learning from the design process. The ability to communicate their thinking with respect to the luge was evident during the focus group interviews and also in their technology portfolios. Central to successful design is the ability to communicate (Bucciarelli, 1994; Latour, 1990). Excerpts from the focus group interviews (conversations) and pages from the student portfolios (glossaries and evaluations) provide evidence of the rich discourse constructed in the class about their own designs, which parallels the findings of Roth (1995). The data from focus groups and student technology portfolios demonstrated that students were successful in recalling and associating knowledge applied during the design process, thus indicating that meaningful connections were being made within the design context. For example, LG and MY recalled the importance of the knowledge of tension and compression which assisted them to identify the weaker elements of their luge, for example to provide metal reinforcements to their frames. LG also commended the approach taken by the teacher towards reinforcing the information on tension and compression in the context of luge design (during Focus Group) as it provided a better understanding of the theory when related to the material testing phase. Students also used this information to explain their design decisions in their portfolios.

It is the interaction between the task, the individual and the settings (physical and social) which leads to the construction of knowledge (Lave & Wenger, 1991). The conceptual demands in such activities should emerge subsequent to procedural demands (McCormick, Murphy & Hennessy, 1994). The students from this classroom developed a functional prototype of a street luge through framing situations in technology which required science concepts or technological procedures to be recognised during the process of construction (Rowell, 2004). That is, the application of knowledge during the activity initiates the inclusion of conceptual knowledge with the procedural knowledge. Students were provided with extended opportunities to develop and use their own ways of talking and thinking about constraints, trade-offs and possibilities of risk and failure. The following section (Section 2) will focus on key instances from the classroom which highlight the integration of science, mathematics and technology while designing and making.

Section 2 - Integration of Science, Mathematics and Technology

7.2 Interaction through Discussions and Prompts

The practices and strategies introduced by the teacher indicate his support of an integrative learning environment in a technological design context. Students were provided continuous opportunities and facilitation through technological discourse which enabled the students to explain and clarify their own meaning and understanding. They learned to communicate their design ideas through actions and discourses which became possible through their active participation in the design process. These actions not only led the students to the final design, but in the process of designing it also interacted with the elements of their surroundings to construct knowledge which included elements of science and mathematics. The following sections will explicitly focus on the factors, strategies and approaches which assisted or hindered integration of science and mathematics in this design context.

Classroom communities may explain by clarifying meaning (providing definition), identifying a causal mechanism (explaining why something occurred), or justifying an idea (explaining why one believes the idea) (Braaten & Windschitl, 2011). The scientific practice of explanation goes beyond defining or describing a named process and links a chain of reasoning to the phenomenon to be explained. Attempts to construct new explanations typically require elements of argumentation to support and challenge potential explanations. Indeed, effective classroom support for scaffolding explanations reflect these elements of argumentation, such as prompting students to support claims with evidence and reasoning (McNeill & Krajcik, 2012; Sutherland, McNeill, Krajcik & Colson, 2006) which was observed in this classroom. The discussions which took place in this classroom demonstrated the potential of the students to explicitly refer to the technological knowledge gained through participation. These incorporated elements from science and mathematics which were implicit or explicit to the students.

The discussions and prompts which were used by the teacher in the classroom/workshop had the potential to integrate science and mathematics which in turn affected the quality of the conclusions made by the students in their portfolios. Instead of making a general claim, the students were able to justify their conclusion using ideas from science and mathematics. An example of this is the momentum testing phase, where investigations were performed with the appropriate controls looking at the variables of the luge wheel (50mm, 100mm and 70mm diameter) with the same pilot to determine what combination would provide optimum speed for the luge over the set trial distance. Analysing the resulting data initiated a stage for discussion and prompts by the teacher in the design room which provided the students an opportunity to think about their choice of the wheels. These discussions involved the integration of knowledge from science and mathematics, which was not purposely introduced by the teacher, but naturally developed in the course of conversation while trying to understand and explain the observed phenomenon.

It can be said that the students made conclusions about their research using information from science and mathematics as the initiative was taken by the teacher to discuss the findings using scientific and mathematical concepts in Stage 1. The excerpts from the classroom discussions indicate how the prior knowledge and experience of students was recalled so they could relate it to the current situation. The technological context of testing wheels through a practical driving experience gave the teacher an opportunity to discuss the findings which resulted in recalling information integrating knowledge from other domains, so creating a learning environment which initiated recall of concepts such as circumference, revolution, resistance and their effect on the speed. Explanatory accounts were developed by the teacher and students which included construction of the argument to support the data with comparision and critique. The explanation provided by some students indicates their use of data as evidence (average times, faster wheels, and circumference). Consequently, the students made design decisions which incorporated this integration in the course of reflection on their experience, rather than the teacher initially teaching science or mathematics concepts through technology. This evidence from the portfolios demonstrates the capability of the students to generate conclusions derived from their observations and calculations, which includes knowledge from middle school mathematics like basic tabulation and calculating the means and from their basic understanding of circles, diameter, circumference and revolutions. Students have indicated this understanding in writing that bigger wheels cover ‘more ground per revolution’ than smaller wheels and so concluded rightfully that they are faster than the smaller wheels. In Stage 1, the concepts of circumference of wheels and its relation with the amount of revolutions were discussed and it formed the part of the context naturally. Here it was observed that attempts were made by the students to construct new explanations thorough argumentation to support their research through information and knowledge from science and mathematics.

These discussions and demonstrations initiated by the teacher provided instances where students raised questions which involved cross-curricular linkage opportunities. In one instance, a student (JS) raised the idea of how the width of a wheel would affect the speed of the luge which gave rise to discussions around weight distribution through the wider 70 mm diameter wheels to the ground. This student demonstrated an understanding in his portfolio of why wider wheels were better than the narrower ones because of their ability to run over stones as factors which provided a better grip and affected the speed of the luge. The ideas from science and mathematics can be seen to be utilised in the context of the product, in other words, his explanation displays an understanding of the component gained through practical experience and attaching meaning from science to justify the observation.

Another occasion where the discussions and investigations provided a context for integration is the material testing phase. The abstract information from science about tension and compression of fibres acting at the top and bottom layer of the plywood and steel was discussed in Stage 1. Scientific concepts of neutral axis and the radius of curvature was introduced to the students during theoretical sessions both in the workshop and design room. Soon after the information was provided to the students, the demonstrations on bending the laminated plywood and steel beam (square and rectangular) were carried out to study their behaviour under loading conditions. This created an opportunity to integrate information from science about tension and compression to reinforce the demonstrations which involved minor mathematical calculations. The discussions which developed from the demonstrations indicate the integration of science which happened while trying to explain the material behaviour which led to its deformation. Students explored the phenomena and, from their investigations, arrived at suitable explanations guided by science principles with support from the teacher. Students were also expected to use the information from testing to make design decisions which led to the integration of knowledge from science and mathematics to support design decisions/explanations and conclusions in the portfolios.

The momentum testing phase and subsequent discussions around the constructed luges provided an opportunity for the students to observe and learn about effective riding positions. The idea of the feet-first riding position and streamlined shape of the luge, which are functional characteristics, led to discussions around the concept of aerodynamics assisting a smoother and faster ride. This provided an opportunity for discussions where students actively took part and indicates that students were successful in connecting science principles like aerodynamics to the luge shape when initiated or encouraged by the teacher. The students gathered ideas on aerodynamics during the initial stages of the project when the sole focus was on understanding the structural functioning of the luge. This was accomplished by taking the students through research, product investigation, concept drawings, classroom discussions, specifications and attributes of the project. The understanding of aerodynamics for stability and steering was demonstrated by the students during the concept drawings in Stage 1. The compact and streamlined shapes of the concept drawings of some students indicate the employment of ideas gathered through discussions about luge components. The students may not have referred to the concepts of aerodynamics explicitly but a closer look at the shapes and assembly of the components reveals the development of observational skills and practical understanding related to the functioning of the components.

The processes of construction provided numerous occasions for discussions to take place on either a one-to-one or a group basis, initiated by either the teacher or the students, where information from science and mathematics was naturally recalled. The emphasis on material manipulation, operational principles and functionality of the components provided an opportunity to recall information from science. An example is when LG realised his initial luge design would have failed as it was not capable of providing enough support to the weight of the pilot. This experience was gained through the interaction of the student with his luge and the expertise of the teacher. The interactions led to a change in LG's ideas and the development of a new design which added extra strength and support to the area where the weight of the pilot was to focus. So these interactions and discussions with the teacher and other fellow students gave rise to situations where students had to consider mathematical measurements and calculations to accommodate the body pans on the frames. This also required technological thinking which incorporated science in a usable and implicit form such as designing for aerodynamics, distributed loading and centre of gravity.

The teacher assisted the students to justify their claims using science and mathematics concepts. During demonstrations from the teacher, the students were provided prompts, guidance and scaffolding to support claims with evidence and reasoning in the design room. For example, the discussions during momentum testing phase involved the use of information from science and mathematics, which was not purposely introduced by the teacher, but naturally developed in the course of student conversations while trying to understand and explain the observed phenomenon. Teacher wanted the students to incorporate ideas from science and mathematics to justify their wheel selection conclusion. The teacher encouraged students to apply their thinking and explanations to the momentum testing phase and material testing phase to draw conclusions based on the information discussed and the demonstrations. The students generated hypotheses through experimentation, personal knowledge, and classroom and personal discussions. It can be argued that the process of scientific argumentation occurred when the students defended their claims that is perhaps a proposed explanation, in doubt or when contested (Osborne & Patterson, 2011) and motivated the participants to defend their own thinking and challenge or question alternatives (Berland & Reiser, 2009). The practices of the teacher to help facilitate students to build technological knowledge also introduced science concepts to provide better understanding of the practical aspect of the design. This involved students engaging in and reflecting on the practices of technology and developing strategies on integrating science through discussions and demonstrations to deepen their knowledge. Discussion, debate, questioning and explanation are some of the activities that have been shown to support active learning and the construction of meaning in the classroom (Cohen, 1994; Laurillard, 1993; Matthews, 1996; Springer et al., 1999). In addition, this study highlights that through these discussions with students, the teacher created a platform to connect their present situation to concepts in science and mathematics which integrated with the work of the students.

These are various episodes which illustrate the significance of argumentation and explanation to integrate science and mathematics when students engage meaningfully with the practices of technology. The spontaneity of these discourses is such that they (teacher and students) are not looking at a textbook, worksheet or under an external constraint (exams or assessments) which suggests that these interactions are natural and meaningful. The students may not be actively engaged in developing detailed explanations, but they desire to have a practical understanding of their observations. There were numerous instances of cross-talk and discussions amongst the teacher and students which engaged them in what appears to be purposeful knowledge construction interactions such as during the material testing phase.

The portfolios reflect the knowledge from science and mathematics being integrated with technology specific to the context. Students explained their observations which fitted in well with the abstract science principles explained during discussions and demonstrations. These conclusions were informed by the detailed information discussed by the teacher during demonstrations using scientific, mathematical and technological terminology. The teacher's continuous use and expectation of the students to reflect the understanding of scientific concepts and terminology led to their inclusion in the portfolios.

The important point to be highlighted here is the utilization of basic knowledge from various domains can happen while experimenting in technology, since this creates a path for an integrated learning environment. Across these examples, student arguments for their explanations using science and mathematics as a tool can strengthen their research and help construct a consensus explanation amongst students such as the effect of tension and compression forces on a body while taking loads. Also in the momentum and material testing phases, the support, defence, and consensus building of the data helped make the explanations more elaborate and precise. Students may not have expressed their understanding by using science principles and terminology while writing the conclusions, but they came to a meaningful consensus about the experiment and reported their findings in an intelligible way. Such experiments should not be downplayed as a trial-and-error or hit-and-miss processes, but rather as the student's interpretation of results resting in the utilisation of knowledge from other domains to interpret both expected and unexpected outcomes in technology. Such experiments whith an element of trail and error encourage students to critically think and interpret the situation at hand.

In summary, engaging students in building arguments and explanation can result in numerous benefits. For example, creating and supporting their investigations can help students develop a deeper understanding of the content knowledge (Zohar & Nemet, 2002). The evidence presented shows that students are capable of constructing explanations which may actively use the scientific principles and mathematics to explain the observed phenomena, thus developing a deeper understanding of the context. By engaging in this investigative practice, students can improve their ability to justify their own written claims (McNeill et al., 2006). The goal was not to achieve learning outcomes from science as a part of this project; students were commenting upon circumference of a circle, revolutions, diameter, tension and compression, aerodynamics and centre of gravity, and an outcome was achieved in terms of integration. Hence, engaging students in justifying their results from investigations is advantageous in developing an integrated learning environment.

The next section will detail the factors which assist or hinder the integration of science, mathematics and technology in a technology classroom.

7.2.1 Intent of Actions and Integration of Science

As already discussed, the intent with which the teacher and his students performed practices reflects the nature of technology. The major emphasis was on developing a functional and aesthetically pleasing luge, using appropriate materials and techniques, and studying the operational principles of the luge components. The information from science and mathematics was not purposefully recalled by the students, but happened naturally within the luge context. Students were able to identify the principles of science and operations from mathematics which they utilised while constructing the luge. This study also shows there were instances in the class where information from science was not considered to be significant while designing or making the luge because of the intent of the students. The students were concerned with developing a working product which required them to employ material manipulative skills to proceed with the design more than to understand science. Interest and goals are central to people's everyday actions and activities (Schank, 1993; 1994). Design is a form of problem solving in which interests and goals are fulfilled by going through a process, which is expected to result in an optimal solution. The nature of the design brief for Gravity Powered Street Luge allowed students to be introduced to the design process and to construct and test knowledge by incorporating their ideas in the design (e.g., Harel, 1991; Harel & Papert, 1991; Kafai, 1994). The following paragraphs will describe instances which led to or hindered the integration of science, mathematics and technology while the students experienced uncertainty in finding, investigating and achieving solutions.

The emphasis on construction by making references to materials, construction techniques and constructed products keeps the focus of the students on the product. Thereafter, the students were more interested in understanding and exploring easier ways to achieve better solutions. This approach forced a reliance on existing technologies and prior knowledge to move forward with the construction of the product, which led to less direct references being made towards science in the class. An example was when the students did not consider it to be important to explain their choice of selecting the 70mm diameter long board wheel over the 100mm and 50 mm diameter wheel sets in their portfolios. Students understood through their prior experience and the collected evidence that the 70mm diameter longboard wheels were faster than the other two wheel sets and made that conclusion without reference to science principles. The evidence from the student portfolios indicates that no student (except JS) bothered to explain the argument based on principles from science. It was seen as unnecessary to understand the reasoning behind the observed phenomenon as it was a common knowledge or prior knowledge (for the students) that longboard wheels are designed to be faster and were made with better bearings.

The majority of the students also claimed that the heavier pilot was faster than the lighter pilot, another example where students relied on the field data to generate claims without supporting explanation. Again, this may be because the teacher did not emphasize the importance of explanation. The literature also indicates that students often have difficulty defending their claims (Sadler, 2004) and tend to write claims without proper justification and reasoning. The students relied on their prior experience and field observation data (for both 70mm diameter wheel and the effect of weight on speed) which influenced their decision-making process and diverted their attention from explaining their claims using science. Students might not have deemed it significant to provide a scientific explanation. McCormick and Davidson (1996) have identified what they call the “tyranny of product outcome” in design and technology classrooms. They argue that the focus on the final product prevents students from going deeply into the design process. Similar results are reported by Mittell and Penny (1997).

In this study, this could also apply to the possible explanation of design choices based on science principles. The way the teacher and students approached the task of choosing the faster wheels is logical from a technological point of view. Thus, both for the longboard wheels and the effect of the pilot’s weight on the speed, students did not consider it to be necessary to explain their claims based on the information from science. These two examples indicate students’ ability to make design decisions not supported through science or mathematics and this occurs more frequently than generating explanations.

The display luge from the workshop proved an important aspect of the learning environment that contributed to the luge design. The display luge was studied in terms of the materials, manipulation techniques, components, functions, and assembly. For example, knowing why and how to create the shape curved of the body pan was more prominent than learning about the physical or chemical properties of plywood. The researcher observed that the presence of the constructed luges in the workshop influenced the students’ designs. This could provide an explanation for why direct references to science were absent during such conversations. The discussions which arose around the constructed products were directed towards understanding the structural assembly techniques to be incorporated into individual designs, rather than to understand the underlying science principles related to the luge functions.

Technological procedural knowledge was more important to students than science and mathematics while designing in technology. Students faced the issue of speed wobbles and steering problems during the initial set of test runs, but it was overcome by tightening the truck bolts. The procedure of tightening the trucks was carried out by almost every student, as is evident from their portfolios, in their desire to steer well with the fastest speed possible. The nature of knowledge was the practical know how of interacting with the various components of the luge to make it work better (operational principles). The knowledge from science or mathematics to explain the rationale for the speed wobbles or steering mechanism had little significance for the students in solving this problem.

The following section will highlight the influence of prior knowledge gained by experience and classroom participation in the integration of science, mathematics and technology.

7.2.2 Influence of Prior Knowledge, Field Observations and Classroom Discussions

Students observed and studied the structural integrity of luges through teacher led and self-initiated investigations and were inspired by the current state-of-the-art luges. The concepts of centre of gravity and aerodynamics were introduced by the teacher during discussions about the sample luge on display in the workshop. The focus on design specifications and attributes provided an opportunity for discussions where students actively took part in referring to science ideas related to the luge. The students were also successful in connecting the concept of aerodynamics to the design criteria requiring a feet-first riding position. Even though the intent of the teacher may not have been to discuss science concepts in this instance, this episode highlights the potential of prompts which can initiate discussions by recalling prior knowledge from science and its application in the design context. The science concepts were recollected by the students in the questionnaires (Stage 1 and Stage 2) and during the focus group interviews as reasons for specific shapes and functioning of the components. The students reported ideas on the centre of gravity, aerodynamics, tension, compression and the structural functioning of the luge during the initial stages of the project and were able to recall or apply these ideas while making the luge.

The use and application of scientific concepts and terminology was evident among the students as a result of its introduction during discussions. Understanding of the lower centre of gravity and aerodynamics for stability and steering was demonstrated by some students while developing their concept drawings during Stage 1. The concept drawings demonstrate the knowledge developed from their prior experiences of riding luges, researching, inspecting constructed luges and classroom discussions. The students were successful in utilising the information from science in the context of luge design, as was evident from the concept drawings. This knowledge was successfully reflected in their concept drawings, which enabled them to understand the rationale for the shapes and assembly of the various components. Not all students referred directly to the centre of gravity concept in their drawings, but a similar understanding existed in terms of the drawn shapes, function and assembly of the components. The compact and streamlined shapes of some concept drawings indicate the employment of ideas related to lowering the pans towards the ground and designing for aerodynamics. The information from science could also be seen in a few portfolios where the students tried to justify the selection of the processes. This indicates the thinking of the students in terms of selecting their material and choosing an appropriate technique in order to achieve the desired functionality of the component. This naturally enabled them to justify their choices with an element of science which was discussed in the classroom. Thus, it is clear that knowledge from science regarding the functionality and structural operations was developed by the students during the initial stages of the project, and they could transfer this knowledge when making their own design decisions.

Some students made no direct references to the scientific concepts while drawing concept diagrams, but they did gain understanding of the functionalities, materials, techniques, components and riding positions. For example, the feet-first riding position was mentioned as a way of reducing air drag and improving aerodynamics (by BA). The concept drawings by BA also indicated a dip in his body pan and frame combination, indicating the influence of the constructed products already designed for the correct clearance from the ground; however, no reference was made to the concepts of centre of gravity and aerodynamics in his drawings. While the students might not have referred to the science explicitly, a closer look at the shapes and assembly of the components reveals that they developed an understanding of the luge along with the shapes and functions of the components. Thus the concepts from science may not be present in their abstract form in student produced concept drawings, but such understanding does exist implicitly in a representational form which relates to the product. This indicates a natural application of technological knowledge with respect to the luge where the functionality of components is understood and obvious to the students. However, the scientific principles associated with the shape and functionality of the components remained implicit to the students but they made explicit references to science principles when asked to identify their application in the product context. For example, JS and NT identified science in the form of forces or weight being applied to the luges, and the distribution of the weight through the trucks plates to the wheels. Also, the students were capable of explaining the problems or issues encountered in the field using scientific terms and conceptsduring the interviews. For example, EM and TG mentioned instances of making minor changes to their luges after testing. He provided an explanation on the basis of the theory of tensile strength and that stress is produced on the truck plates while speeding which indicates references to scientific terminologies and concepts in the context of technology.

The students applied the knowledge of the product gained during the design stages by appropriating procedures and techniques which incorporated implicit application of scientific principles. For example, the lowering of the body pans to the ground by placing them on the frames (wooden and steel) was evident during the construction phase. As indicated earlier, this technique of construction was reflected in their concept drawings and was gathered from the existing luges, the internet and the workshop (through discussions). The students indicated this understanding of the underlying shape and assembly of the chassis and were able to link it to the principles of centre of gravity and aerodynamics. The construction of the frames required critical thinking about materials, the alignment of the body pans and the elevation required to achieve the correct clearance from the ground to ensure a safe and effective ride.

Knowledge about the properties and strengths of the materials from previous years was also recalled by the teacher and the students which helped to develop a better understanding the components and their assembly. This was achieved through discussions, developing an understanding of the product in terms of the assembly of the various components, their functions, and the materials and processes involved in making and fixing the product. The procedural knowledge of constructing the body pan and frames in addition to the conceptual thinking of the alignment techniques was achieved through a trial and error approach. It is worthwhile to note that the concept of centre of gravity and aerodynamics might not have been referred to by the students during construction, but they showed some understanding of those concepts by employing the techniques to construct them, which is the essence of technology. It can also be said that the students might not refer to science concepts explicitly during construction, but could make logical connections to the aspect of the project where the science concepts aligned well.

Students could recall the scientific and mathematical concepts they had discussed earlier when the time came to apply them. The integrated knowledge of the theory of bending with a focus on tension, compression and the radius of curvature was provided (in Stage 1) and recalled by the teacher and students in Stage 2 and Stage 3. The focus group interviews indicate that the students could relate the information from tension and compression to the body pan and frame construction as they became more familiar with the information (tension and compression) and context over time. The student's portfolios show evidence of how they explained the investigations using scientific terminology and language such as 'tensile strength', 'centre of gravity', 'force', 'neutral axis, 'radius of curvature', 'pressure' (referring to force) and 'tension and compression'. The analysis of the students' work during the material testing and construction phase suggests that they made rich and varied associations after the information on tension and compression was provided. Students demonstrated potential to integrate the experience (Roth, 1996) and knowledge they had prior to construction, with the new information to make meaningful connections.

There was some evidence that students could recall and apply science related information while working on their body pans and frames in the workshop without the teacher reminding them to consider this information. The evidence is the addition of braces on the chassis by the students as an application of the information from tension and compression. This suggests that students thought in terms of the structural integrity of the luge. They did this by assessing the feasibility of the original concept in terms of material strength and identifying weak sections of the frame to provide appropriate reinforcements according to principles of tension and compression. These are the forms of representations that students will understand and can attach meaning to because they are part of the same world (classroom and the context) as the constructed artefacts and events they have designed.

Designing technological artefacts allows students to realise their ideas and, while doing so, may recall, utilise or refer to scientific and mathematical concepts. The design thinking occurs in a context as ideas are concretised into material elements which present constraints. Asking students to produce artefacts from their own design demands feasible design ideas and motivation towards pursuing the task. The students wanted to express their design ideas developed through adopting the practices of the community. A technological product has different underlying science principles which can be made explicit to engage students during discussions and demonstrations. The possibility of students acknowledging and applying these science concepts while writing conclusions and during verbal communications cannot be ignored. An important aspect of the teacher's work is then to help students identify those instances that are relevant to science and which are crucial for making the science-technology link succeed (Roth, Tobin, & Ritchie, 2001). Such an approach can be significant in implementing an integrative learning environment where scientific principles and ideas can be recalled when required or deemed significant by the teacher.

Students who sustained an interest in designing and making their product developed competence in talking about their own designs. It is the conversations which provided a context for developing and participating in a communal discourse (Roth, 2001). This discourse arose from the focus on designing and developing a functional luge which incorporated interactions among the actors and which led to the natural and purposeful integration of scientific concepts and principles. Depending on the nature of discussion around the product and the accessibility of the abstract knowledge from science and mathematics, the teacher took appropriate measures to evolve the discursive practices to become scientific (e.g., Roth, Tobin, & Ritchie, 2001). The nature of the project provided students with many opportunities to use their language (both technological and scientific), to talk about their interests relating to luges, to design and make the luge, and to suggest future improvements.

When students present, discuss, argue and critique their designs with others, they are more inclined to be able to identify the scientific principles that are related to the operation and structure of the product. Participation in practice is known to be powerful in learning the practice and constructing the identity of a practitioner (e.g., Lave, 1993). The focus of the practitioner is governed by his/her intentions and participation in the practice of making a product, which can create opportunities for learning about principles of operation and design in addition to the underlying science and maths concepts.

Rather than being taught the abstract science principles, students could tinker with materials and components until their devices can do what they intended them to do. There is evidence that this form of technology lesson would not lead to the emergence of scientific discourse (e.g., Roth, Tobin, & Ritchie, 2001), since the intent is to produce an artefact. That is, if students are just working with materials and not forced by the situation to also represent their ideas through discussions, drawings, experiments, trial and error procedures; scientific discourse (including talk about mass, momentum, aerodynamics, centre of mass, and tension/compression) is not likely to occur. However, when students have to learn about the assembly of the product, experiment and investigate the behaviour of the materials and the various operational principles which require articulation and explanation, they have to represent their understanding in a form that is accessible to the rest of the community. This may initiate the recall of relevant science and mathematics information (abstract forms) within the design context.

Technological activities with a focus on design allow students to become involved in creating and transforming knowledge in technology. They are also deeply involved in activity and therefore in the transformative aspects of knowledge. For many products, the individual elements and the relationship among them can be described and explained to a large extent using scientific principles and mathematical tools. This, however, is not usually the intention with which a student starts to create an artefact, but it is the technological concepts and knowledge which determine the functioning of the artefact, its artistic value, and so on which is the student's intent. This stage appears to be promising for introducing science through technology-related activities as it can affect the designed outcomes. Because technological activities provide grounds for initiating and developing scientific discourses (Roth, 2001), it could be utilised as a platform to integrate science and mathematics if there is a legitimate reason to do so. Technological activities are, therefore, appropriate for an integrated approach to teaching, for they can provide the core activity in which students engage in a variety of discourses and which science and mathematics elements could be naturally integrated.

7.2.3 Design Development through Trial and Error, and Curiosity

Ethnographic research has shown that a practitioner's knowing is always richer than any description of it; and knowing how to do something does not necessarily make for skilled performance (Beck & Kosnik, 2001; Schön, 1983; Scribner, 1984). There is evidence to suggest that the ability to recall prior knowledge and cognitive skills is not an abstract and context-free competence that may be easily transferred across diverse problem domains, but rather consists of cognitive activity tied specifically to context (Çimer, 2007; Greeno, 1989; Rogoff, 1984). The design context includes the activity's physical and conceptual structure as well as the purpose of the activity and the social domain in which it is embedded. Thus, objects (tools and resources), events, meanings of terms, and a person's cognitive activity are a function of the situation (Engeström, 1987; Greeno, 1989). Effective practical problem solving and skilled activities such as material manipulation, tool related practices, and testing may proceed through the use of tacit knowledge rather than through a systematic application of prescribed steps (Rogoff, 1984; Schön, 1987). It follows that learning methods embedded in context are not merely useful; they are an essential part of the design. The contextual knowledge arising out of such practical activities cannot easily be replaced by its descriptions (Brown, Collins, & Duguid, 1989; Schön, 1987; Suchman, 1987). The contextual knowledge embedded in the luge context was a rich mix of procedural and conceptual knowledge which had elements of scientific and mathematical concepts taking a contextualised form.

The knowledge constructed by the students which is situated in the context is a rich non-verbal description of action and mental representations developed while experimenting with or participating in the context. The correct positioning of the steel rods or wooden frames in the cardboard pattern prototypes are examples of thinking in terms of weight to be supported and distributed to make the luge structurally stable. It is the context which enabled the students to interact and to initiate experiments to identify variables which could affect the performance of their product. During the construction phases, students continuously referred to their cardboard prototype (2-Dimensional sketches) to determine the positioning of the steel rods beneath the body pans, in reality, through a trial and error approach. The positioning of the rods beneath the wooden frames was not predefined in some specifications or dictated by the teacher. Thus self-initiated experimentation in technology afforded opportunities for the students to shift their mental representations to the real world and, in this process, encounter constraints to be solved using a trial and error approach. This is when the students realised the practicality of their design ideas where general know how and tacit knowledge on its own cannot solve the problem. Such situations require detailed analysis and logical thinking around the problem within its context. The use of cardboard patterns to identify the positioning of the body pans and frames (their size and position) to incorporate the level of clearance from the ground is another example of efficient problem solving in technology through thinking and experimenting and technological modelling.

Then, over the course of researching, working and experimenting in the same physical, conceptual, and social context for several weeks, the variables affecting the performance of the luge became clearer to the students. A few examples are the conceptual change in cardboard patterns (mock up models), designs and constructional techniques. The development of procedural knowledge by students (MQ's procedural knowledge of getting elevation on wooden frames) was achieved due to an emphasis on the process testing phase (tool-related manipulation) and the freedom to choose their own techniques to investigate in the workshop. There were instances in the workshop where the interaction of the students with their own product resulted in an improvement of the design in terms of its structural integrity. The curiosity of MQ to loosely assemble the luge components to check the regions of bending on his frame is another instance where self-initiated experimentation resulted in the identification of variables crucial for the performance of the product. Students did not start with a definite idea about the variables, but through their curiosity, conversations and experimentations they negotiated the variables to improve the design. As the familiarity with the context increased, the students identified more of the factors and variables which would affect the performance of the luge. For example, while making the cardboard patterns, LG thought in terms of the structural integrity by recalling the principles of tension and compression. The concept of aerodynamics was referred to while making the cardboard patterns by a few students in class.

The interaction of the students with the design environment can also present constraints and problems which could assist the integration of science, mathematics and technology. Resolving such problems may require critical thinking with an element of trial and error around the properties of the materials and components, assembly of components and structural behaviour (like the tightening of the trucks to eliminate speed wobbles). Through various trial and error and iterative processes, students were able to provide meaning to their actions and employ these actions (practices) through participation in the community. For students trying to mark the position of the truck plates to the frames, lowering the chassis, and designing the nose cones involved considerable thinking about the placement of the components to attain maximum stability for the luge. This was attained either by following the prescribed method dictated by the teacher or, as some students did, by experimenting and going against the prescribed teacher-dictated rule and still managing to attain a structurally stable luge. Students' abilities to identify variables and factors affecting the performance and assembly of the luge improved with the number of trials they performed within the specific context (one example would be getting the correct clearance of the frame). Such improvements can be attributed to meaningfulness, familiarity, and similarity, the three factors that improve students' success in applying skills to problems (Simon, 1981).

The following section will illustrate the significance of demonstration with appropriate scaffolding through theoretical support in a technology classroom.

7.2.4 Theoretical Sessions with Demonstration

In the activity which is the focus of this study, students were given the responsibility and the freedom to design their own luge. It was found that they successfully chose their design, methods for data collection, and subsequent analysis, materials, tools, manipulative techniques and testing procedures. In order to benefit completely from such freedom and independence, individual students had a support structure, which was provided by the cooperative learning environment. Throughout the phases of the development, the students discussed, negotiated, and worked on their product. Opportunities were provided by the teacher to learn appropriate tool-related practices and material manipulative techniques. During the planning session, the students cooperatively decided upon the materials and properties to be learned, the tools to be used, the events to be observed, and the manipulative techniques to be employed. Spontaneous ideas and information where shared with the other members of the group. The peers (students and stakeholders) then critiqued and reported on the flaws in the plans of other students or developed their own designs by elaborating on initial ideas. Throughout the planning, design, material selection and testing, process testing, cardboard patterning, luge construction, final product testing and the writing of the report (portfolio), a cooperative learning environment was developed. The teaching-learning situation under study was premised on the idea that activity and context are integral to learning (Brown et al., 1989). In the present case, students attended a classroom environment where they engaged in meaningful problems where the activity and context are intertwined. Students were provided opportunities to learn by scaffolding, technological modelling and reasoning. Consequently, deep understanding was likely to develop because students are solving authentic problems (Brown, Burton, & de Kleer, 1982) in a design context. The students employed procedures which demanded practical and conceptual knowledge and hence it can be said that such understanding is anchored to a personally meaningful context which can be recalled more easily than isolated bits of knowledge (Brown et al., 1989).

Students' interpretation, analysis of data, material manipulative techniques, tool-related practices and results became increasingly elaborate as they went through the phase of appropriation, technological modelling and fading. Gradually, the students developed the ability to transform the verbal instructions and demonstrations from the teacher to actions through either prescribed steps or practical iterative processes that involved conceptual thinking. The thinking skills involved the transformation of information and its application to a real life context. The students in this study, however, not only designed and constructed a luge but were also able to undergo the process of developing procedural and conceptual knowledge to become members of a technological community. The students, through satisfactory employment and interpretation of the procedures, had constructed new knowledge, by its application in its usable form, and communicated their findings. Contrary to the silo approach taken by many subjects in schools, this embedded approach encourages learning through various contexts and problem representations (Rossouw, Hacker & de Vries, 2010).

The cooperative learning environment, with discussions, experiments, investigations, researching, designing, construction and testing, supported the construction of individual knowledge of the members in a variety of ways. Brown et al. (1989), Brown, Collins & Duguid (1996) have indicated that social-interactive teaching methods show great promise and this resonates with this study indicating the potential of incorporating cross-disciplinary knowledge. When students are required to discuss, explain, conclude, elaborate, or defend their positions (as they did in their luge evaluation reports), they are more likely to construct a deeper understanding. (Brown et al, 1989; Hatano & Inagaki, 1987; Scardamalia, Bereiter, McLane, Swallow, & Woodruff, 1989; Tobin, 1990). In addition, learning through experiments and investigations gave rise synergistically to insights and solutions that would not otherwise have about and constitute a powerful mechanism for integrating science and mathematics in the design context.

Extensive theoretical knowledge and discussions without proper demonstrations and sufficient scaffolding may hinder learning in technology. For example, in the procedure of determining the weight distribution, students were made aware during the discussions in the design room that more weight should be applied on the front wheels to achieve better steering. The focus of the teacher was to get the correct weight distribution on the luge by making the students follow a prescriptive procedure which was covered theoretically in the design room. The interest in duplicating the prescriptive process of weight distribution may not have been strong as it was considered to be complex by the students or was hindered by extensive theory and mathematical calculations. While the students could follow the instructions provided by the teacher to obtain the correct positioning of the trucks, they were not successful in applying the procedure in the workshop. Another effect was the miscalculations made in the weight distribution ratios (for example by DR who did not follow the teacher prescribed procedure) which became obvious when unacceptable sag was observed in the frame which could affect the steering and riding of the luge. The painstaking process of getting the correct weight distribution may also have been overwhelming for the students because of the calculations involved or due to the lack of specific demonstrations.

The interaction of the actors with the environment provides opportunities for referring to science and making conclusions using mathematics as a tool. The use of mathematics in this design context was extensive in the form of basic tabulations, calculations and operations performed while designing and making the luge. The following section will define and clarify the integration of mathematics in a technological design context with its real purpose and consequences in design during its application.

7.3 Purpose of Mathematics

It is known that scientific and mathematical ideas are used in 'design-and-make' activities in the design and technology (D&T) classroom and that this context can provide a good opportunity for developing pupils' understanding of these ideas (McCormick & Evans, 1998). There are discussions about the pedagogical implications and opportunities of this use of science and mathematics (e.g., Burghes, Price, & Twyford, 1996) in a technological design context, but there are few accounts of how teachers and pupils actually use mathematics. Findings from a number of studies have also shown that the strategic use of technological tools can support both the learning of mathematical procedures and skills as well as the development of advanced mathematical proficiencies, such as problem solving, reasoning, and justifying (e.g., Gadanidis & Geiger, 2010; Kastberg & Leatham, 2005; Nelson, Christopher & Mims, 2009; Roschelle et al., 2009). Teachers believe that to teach mathematics in an outdoor setting motivates the children more than solving problems in textbooks, thus offering new ways to introduce and work with mathematical concepts (Lövgren, 2007). A study conducted by Nilsson, Sollerwall and Milrad (2009) suggests that there needs to be a balance between mathematical theories and technological practices, where practice takes on a rather dominant role. Nilsson et al. (2009) also recommends that as the project and iterations proceed, the role of mathematical theories may be increased in order to enhance control of the learning activity. The data from this study suggests similar findings and will highlight the various instances where the application of mathematics was identified while designing and making.

During the design and make stages of the project this research examined, it was discovered that abstract mathematics could be used in technology, but their use was very basic if compared to what the students study concurrently in their usual maths programmes. The following paragraphs discuss the utilisation of mathematics (topics and processes) within the technological design context, and the problems with students' use of mathematics in this context. Several examples will be provided of mathematics being used by the students in technology to highlight the instances which led to such integration. This study will also identify and discuss several areas where links between technology and mathematics were not recognised or made explicit.

In this technology classroom, there was a real purpose for measuring, and there were consequences if errors were made. The luge design context presented many opportunities and challenges to the students in the form of basic mathematical skills. For example, when students recorded the data from the field trials initially, and then discussed those results in the design room, this gave an opportunity to think about and reflect on their field observations. Investigation carried out during the momentum testing phase naturally created an opportunity to integrate mathematical operations. This included data collection, calculation of average time, analysis and drawing conclusions based upon the available statistics. The use of mathematics was not extensive or to a high level, but rather as a tool to tabulate and analyse results. This represents quite basic mathematics compared with what they were concurrently studying in their maths classes. The technological design context affords real opportunities for handling data through mathematical operations and principles which could be reinforced during the processes of design and make to maximise opportunities.

The teacher understood the link mathematics had with technology but did not make this link explicit in his classroom. He did not acknowledge that there could be a connection between the processes he was teaching and the students’ prior knowledge from mathematics classes. The concept drawings of the luge components and the orthographic projections were treated by the teacher as procedures to design the luge, and the use of mathematics as a tool was evident. The teacher went through each procedure with the intent of providing a three dimensional view of the luge without explaining or detailing the steps involved in drawing parallel and construction (datum) lines. For example, this occurred during the basic calculations (in millimetres and centimetres) and lines of symmetry involved during the sketching of drawings and cardboard patterns. Even the procedure of welding pieces of steel at an angle of 45 degrees created an opportunity to integrate concepts from mathematics into the context of technology. The focus was on the technological procedural knowledge required to develop the product, and during this process the conceptual knowledge from mathematics was being naturally applied by the students.

The application of mathematics in designing and making projects which is directed towards creating a product can serve functional purposes. In a mathematics classroom there might be no direct consequence except the answer may be wrong, which might be discovered when the answers are checked with the reference text books, friends or with the teacher. In the technological design context, inappropriate measurements and calculations can lead to adverse effects on the functionality of the product. For example, the procedure of tracing the cardboard pattern on to the plywood involved drawing lines of symmetry with appropriate measurements. The maximum and minimum heights of the individuals involved in riding the luge were measured by each student to incorporate into their cardboard patterns, to make the luge a custom fit for the rider. The cardboard pattern served as a customised pattern through which continuous references were made to align the components of the luge (body pan-frame assembly). The weight distribution process required precise calculations (percentages and ratios of the total weight) to determine the position of the front wheels so the luge would be safe and achieve an effective speed. Students also commented on the significance of getting the precise measurements during designing and making stages. Incorrect calculations could have unfortunate results, as seen from DR's example of not calculating the percentage of the total weight. Just as mathematics is concerned with the illustration of principles, this also applies to technology projects, where there is a focus on physical products (McCormick &

Evans, 1998). The emphasis on product outcomes has advantages and disadvantages (McCormick & Davidson, 1996), but it creates quite different socio-mathematical norms (Yackel, 2001) in relation to what counts as good mathematical procedures. This study has previously commented on how the measurements were applied and judged not by a 'right' or 'wrong' answer, but by the success of the fit of a part or product, which was based on conceptual thinking and procedural knowledge. Similarly, the accuracy of a measurement is guided by the intent of making a custom fit product, unlike in the mathematics classroom where it will more likely be directed at the illustration of a number principle (e.g. rounding of decimals and quadratic equations).

The students applied mathematical operations in a variety of ways, from describing and analysing data, to building models and prototypes. As Dewey (1938/1963) asserted that all education should be grounded in experience, a technological design context seems to be appropriate for the relevant application of mathematics. Perhaps such an approach requires no intentional implementation as this happens naturally where a connection between mathematics and technology education naturally exists. The application of mathematics in this technology classroom was relevant since it aligned with the students' interests of designing and making the luge. It is the distinct nature of the two disciplines which calls for productive ways in which technology could be taught to the students so they learn to design a product and to apply accompanying mathematical concepts. This was achieved by having students participate in an authentic learning environment where real problem situations and solutions have consequences.

Students were highly engaged and on task throughout the project displaying enthusiasm in being creative and constructive for the purposes of designing and making the product. As Merrill et al., (2008) noted in their study, "students take technology education courses because they are fun and activity-based, not mathematics or science-based" (p. 61). The application of mathematics was observed in this technology classroom and naturally formed the part of the context. This finding is supported by evidence from classroom observations (during cardboard patterns making and concept drawings) and focus group interviews (identifying the principles). In a study by Norton (2008), he observed that the teachers had the perception that by linking the learning of mathematics to the technology projects, students could see the value in learning mathematics, that is, mathematics having a purpose. In this study, students identified examples of the application of mathematics during the initial stages, which indicates acceptance by the students that knowledge from mathematics forms a part of a technological design context.

The students experienced more time within the context and opportunities to engage in mathematical activity while designing and making a functional product. Students and the teacher cited examples of their use of mathematical concepts and operations performed while they planned and constructed their artefacts. The role of mathematics in this technology design context is that of a tool which assists the student to understand critical dimensions and to build a customised product. In constructing their artefacts, the students were using mathematics in planning and working with materials that they might not normally engage with in a traditional mathematics classroom. Thus, it was evident that the engagement with an authentic context which integrated basic mathematics gave students opportunities to apply mathematical concepts (basic calculations, ratios, proportions, symmetry, geometry) in a practical situation. What became apparent was the extensive use of the application of mathematics concepts and understanding underpinning the construction and explanation of the behaviour of components. Students identified and solved practical problems which involved addition, subtraction, multiplication and division with whole numbers, decimals, percentages, rates, selecting from a range of computational methods, strategies and known number facts. Students also analysed experimental data and compared numerical results with their predictions to inform judgements about the likelihood of particular outcome. For example, while analysing the results from momentum testing, students identified that the difference in the readings was not significant and inferred that the readings should not make much difference on the dependent variable (speed). Almost all students had evidence in the form of field recordings from the trail runs to perform a basic analysis to conclude similar results. The technological design context involved students in investigations and experimentations which required data to be collected and analysed using basic mathematical principles.

This study proposes that developing technological design contexts which are real, purposeful and useful is an important factor in engaging students, and naturally entails the use of mathematical operations. The models proposed by numerous authors suggest that that student perceptions are central to their participation and learning of subjects (Ethington, 1992; Khoon & Ainley, 2005; Markku, 2002; Murphy & Gibbs, 1996; Thomson & Fleming, 2004; Wigfield & Eccles, 2000) and that these perceptions are formed early and that early experiences are important (Thomson & Fleming, 2004). The findings from this study are therefore encouraging for technology educators. Technology can be used as a platform to positively foster student attitudes towards mathematics and can be applied to relevant design contexts. In the study, the students were able to recall the concepts and operational techniques from mathematics mainly in the form of basic calculations and measurements when explicitly asked to do so during the focus group interviews. The links between mathematics and technology do not need to be made explicit to the students, as it naturally happens through their participation in the ideation and design actions of technology practice. The use of mathematics was as a support and extension to the project as the measurements were crucial for customisation. The introduction by the teacher of mathematical concepts was not extensive during the design and construction phase except when parallel and symmetric lines were discussed. The teacher was able to bring mathematics to bear when the students needed it. His approach was much more a just-in-time use of mathematics teaching, when the need was identified. The use of authentic contexts tends to enable students to develop reasoning capacities that need contextual mathematizing and the conceptual use of mathematics (e.g., Nason & Woodruf, 2003) which will largely depend upon the type of technology project. Allowing students to make decisions in an authentic design context could afford opportunities to apply mathematics. As previously signalled, the integration of mathematics through engagement with the technology project has the added dimensions of viewing mathematics as a tool (which the students did) to solve technological problems. This also has an added dimension of viewing technology as a platform to explore the world of maths, even though it was not a goal in this design project.

Section 3- Thinking and Reflection

7.5 Reflecting One's Own Thinking

Before the 1950s, many technological inventions and innovations did not rely on scientific theory for their development; however, scientific theory is now becoming increasingly important within technological development (LaPorte & Sanders, 1993). This connection between science and technology inspired even science educators to ask themselves "whether technology-centered activities afford a learning environment that scaffolds students' learning of science" (Roth, 2001, p. 768). The Ohio's new learning standards in science (2011) identify various instructional strategies and resources which include methods designed to engage students to help them gain deep understanding of content through scientific inquiry, technology and technological and engineering design. Under the new framework, students are expected to solve science-based engineering or technological problems through application of scientific inquiry. Within identifiable scientific constraints, students are expected to propose or critique solutions, analyse and interpret technological and engineering problems, and use science principles to anticipate effects of technological or engineering design. Careful steps are taken to identify effective instructional methods which incorporate science inquiry through design and technology. This study has already indicated the potential of technology to integrate content from science and mathematics. Sidawi (2007) mentions that students are expected to draw on their knowledge of other areas of the curriculum (including science and mathematics) to develop and improve their designing in technology. However, the knowledge from other areas of the curriculum which naturally integrates or is purposefully integrated has to be carefully contextualised to indicate the relevance of the knowledge. As Layton (1991) noted, in the ideal world, science explains the natural world and the physical phenomenon but not the practical challenges of its application in real life situations. The challenge to the designer is then to convert the abstract scientific principles to a usable conceptual form within the technological design context.

The technological context of designing and making entails its own conceptual knowledge distinct from scientific knowledge (e.g., Johnson 1997; McCormick 1997). From a science perspective, technology provides a context through which students can apply their scientific knowledge. In contrast to what Sidawi (2007) said, science does not necessarily provide conceptual knowledge which is required by the students to develop their design, as they could have designed the product without making reference to scientific knowledge. There have been instances in the classroom where information from science or mathematics was either naturally or purposefully integrated to acquire a better understanding of the observed phenomenon so students could implement the new understanding in solving problems through design. Students were able to recall information from science and mathematics when explicitly asked to do so while designing and making, and the same behaviour was confirmed during the focus group interviews. The following sections will illustrate the identification of the science principles and concepts by the teacher and students and their reflections of the reality. The next sections will discuss learners' awareness of their own thinking through reflection and critiquing their own knowledge.

7.5.1 Reflection on the scientific principles and their application

The path taken by the students and the teacher was driven by the goals they have in designing and making in technology. The students began their investigations around their technological interest with a goal of designing a product and improving its performance as they designed. While doing so, they also understood the principles of making and operating the product which leads to the formation of general and socially acceptable material manipulative techniques, theories and principles which are technological in nature. This technological knowledge included a component of science (introduced during Stage 1), which was identified and recalled by the students. For example, ST and JP identified the science concept 'centre of gravity' and claimed, as a result, to design a luge with a lower centre of gravity during the luge research phase. Also while making the cardboard patterns, LG thought in terms of the structural integrity by recalling the principles of tension and compression. The concept of aerodynamics was referred to while making the cardboard patterns by a few students. The investigations around luge design created an opportunity to integrate science concepts and these were recalled by the students during construction and after the completion of the project. These strategies helped students to visualise and decide upon the assembly of the components to make it structurally durable. This reflects the nature of technological knowledge. Students were able to reflect on and critique the knowledge they had developed and were able to identify the science associated with the technological knowledge.

The understanding developed from experiments and investigations around materials and their manipulation was evident in the work of the students in the workshop. Technological products are a result of human beings' interaction with objects and materials, understanding these materials, thinking about them, gaining experience with them, and using them to make things (Gardner, 1997). It is through these interactions with the objects and the materials that opportunities are created to introduce science and mathematical concepts to provide meaningful explanations. It is also interesting to note that no initiative was taken by the teacher to make students recall specific science concepts while making the components in the workshop because they recalled the science knowledge provided during demonstrations. This shows the effectiveness of integrating conceptual knowledge in technology. The students could make rich and varied associations after the information about tension and compression was provided to them verbally and practically demonstrated. Students could integrate their practical experience (Roth, 1996) and the science concepts they gained prior to construction with those provided during construction. These enabled them to make meaningful connections when explicitly asked to justify their practice.

7.5.2 Awareness of the Application of Science

The scientific concepts integrated during the design phase of the project were contextualized during discussions and demonstrations. The application of the scientific knowledge through demonstrations assisted students to recall similar scientific knowledge in different contexts when explicitly asked to do so during the focus group interviews. Students provided enough evidence to conclude that they utilised scientific concepts while designing and making their products, and provided justification and scientific reasoning while reflecting on their design decisions. For example, during the focus group interviews, LG, EM and MY clearly made references to the term 'centre of mass' which was introduced by the teacher in Stage 1. Students did realise that centre of mass is an important factor which provided better control, stability and speed for the luge. LG referred to the terms 'centre of mass' and 'aerodynamic resistance' and provided a logical explanation of its application to the luge. The scientific concepts introduced during the initial discussion stages of the project had an effect on the design decisions made by certain students. The structural and engineering theory of the product assembly was understood in terms of principles from science. Students seemed to understand science when it was connected to real life applications and this approach tended to find a place in their discourse. For example, TG's concept drawing shows evidence of considering the centre of gravity during the initial phases of the project (Stage 1). During the focus group interviews, TG stated that a lower centre of gravity is required to keep the pilot stable while riding the luge, which indicated his understanding of centre of gravity. The ‘overturning’ terminology was introduced by MQ during the interview when asked for his rationale for lowering the body pan, and he identified the ‘turning effects’ the luge can experience without proper clearance, which reflects a good understanding of the scientific concept. It seems that the students could increasingly refer to the scientific understanding of the mechanical systems as they gained more experience with the luge context. To be able to capture the complex factors that are involved in taking the theory of science (centre of gravity, aerodynamics) and connecting it to the production of a functional luge, indicates an applied form of science in a technological design context.

The students realised that the abstract form of science was not readily applicable to technology. They needed to create a new body of knowledge to serve as “an intermediary between abstract science and practical action” (Layton, 1991, p. 49). Students were successful in explaining their rationale and actions and could relate the scientific concepts with the actions performed in the design-room/workshop. For example, LG commented on the concept of centre of mass in theory, and its incorporation into practical application involving an element of trial and error. The initial luge research from the portfolios of LG, MY and EM provides evidence of scientific thinking (centre of gravity in the form of low riding positions) and they incorporated this understanding into the design of their frames. Students also referred back and made a connection between their practices of lowering the frames with the science of attaining a lower centre of gravity in the context of frame design. JP referred indirectly to the concept of centre of gravity (by making a frame lowered to the ground in the concept drawing) which made his luge look streamlined (for aerodynamics). This was accomplished by providing a sharp flat plate at the front of the luge (for aerodynamics) to achieve higher speed (mentioned by JP during the focus group interviews). A dip in the positioning of the body pan (from the concept drawings) by ST and JP indicates an understanding of the need to lower the chassis.

The concepts and principles from science were elaborated on by the students during the interviews. Layton (1993) argued that in order for students to be able to articulate their scientific knowledge in action, scientific knowledge has to be reshaped, contextualized and reformed. Students did not rely directly on the use of scientific knowledge to design and make the product, but on the technological knowledge and skills which afforded "recontextualizing" of that knowledge (Layton, 1993, p. 59). In this study, the students were able to articulate their practical understanding and identify the reshaped, contextualised and reformed concepts relating to scientific knowledge. The students did not view the knowledge from science as abstract and detached from context, neither did they separate knowing from doing (Brown et al., 1989), but contextualised the abstract with the action.

The integration of science, mathematics and technology in a technological design context is shaped by many factors such as the common task that the class is performing, the resources and practices that the students share, and the pattern they follow in sharing their ideas. Within such a design environment, interactions take place continuously when sharing tools, materials and resources (Sidawi, 2007). The students showed a clear understanding of the rationale for their designs and could justify choices using concepts from science when explicitly asked to do so during interviews. This indicates that the application of science was evident to some students during the design and construction stages since they specifically indicated its stage of application during construction. This can be attributed to the deliberate approach taken by the teacher to integrate information from science while performing investigations.

Students also tended to design and construct in a technology classroom without thinking about science principles. The knowledge they used to design and make takes a different form from science or mathematical knowledge. However, they did not immediately realise the practical application of science when they were actually designing and making the product in technology. For example, JS, JV and NT did not identify any science being utilised during the luge research and concept drawing phases. However, they identified the scientific reasoning behind the lowering of the pans during the focus group interviews. In another instance, TG mentioned that his frame was bent too far after he positioned his trucks and tested them, and did not initially identify any scientific reasoning. On further questioning, however, he suggested the concept of centre of gravity was behind the issue he faced while testing his luge. The students also confirmed that they did not think in terms of science while doing the luge research and while making the concept drawings. In contrast, JS mentioned that his concept drawing was done keeping in mind the aerodynamics factor which indicates some students referred to science principles while designing.

Neither JS nor NT referred to scientific concepts and principles such as centre of gravity or aerodynamics during the focus group interviews, informal conversations and the student questionnaires. However, their reflections on the designs from portfolios indicate that a practical understanding was developed in terms of operational and mechanical principles which undermined the implicit component of science. Students could reflect on their reasoning without realising the science they might have applied. A detailed analysis of student practices reveals that they consider the content from science and mathematics as irrelevant from their perspective, as it does not directly contribute to the technological activity. This study assumes that from some students' perspective, conceptual knowledge from science and mathematics are secondary to the technological knowledge required to design and make the product.

The knowledge the students developed of their product assisted them in engaging in discursive practices which are associated with conceptual knowledge (McGinn et al., 1995). The knowledge developed was displayed by the students as drawings, material testing conclusions, cardboard patterns, forces acting on the chassis, component designs and through communication. Similar to the study reported by Roth (1995), students shared resources through cooperation and collaboration (facts, ideas, and artefacts) in this technology classroom. However, Roth noted that the discursive practices were not easily appropriated by the students through practice in his class. In my study, students were able to refer directly or indirectly to scientific and mathematical ideas and were also able to explain and justify their luge structural assembly using such principles. For example, JV was satisfied overall with the ‘streamlined’ shape of his luge (as mentioned during focus groups) but also suggested he could have positioned his trucks wider than he had in order to make his luge more ‘aerodynamic’ and structurally strong. These terms could be said to be technological and scientific. Students made direct reference to operational and structural concepts (design concepts) and could provide suggestions for improvement which were based on scientific concepts, in order to make their product stronger and faster.

The information from science and mathematics was not applied by all students. Sidawi (2007) claimed that without the knowledge of science concepts, students will not be able to design technology that draws on these concepts. This study indicates that the concepts and principles from science and mathematics were utilised by the students, but not always with explicit intent. An explicit knowledge of the relevant science concepts is not always necessary to design and make the product, as some students followed the prescribed procedures in which the teacher had incorporated relevant science knowledge.

The other components of technological knowledge that were essential for their ability to design included knowledge of how to operate a drilling machine, lathe, saw or how to weld. These proved to be more essential to design than relying on science concepts. Learning the properties of materials by using science principles formed a part of the conceptual knowledge. In essence, the conceptual knowledge acquired by the students while designing had a component of science which was identified by some students and not by others.

Some students could align the information from science with its application to the luge context. Even the students who could not do this followed similar procedures as those who were able to identify the science information. Familiarity with the context is acquired dynamically through continuing participation in the discourse of a community, not primarily through a set of problem-solving skills and conceptual structures (Pea, 1993). In a study conducted by Roth (1996) where students created various structures as a part of a design unit, he noted that students displayed various dimensions of expertise in a classroom. From Roth’s study, some could identify features like stabilization and others could not. Some students from my study could not identify or align the information from science with the luge context, but this does not make their designs unusable. This suggests that students show varying degrees of an ability for identifying science and its application, even though all could still construct a working product. This study also suggests that students do not view technology as a means to apply science, but a platform to design and make a working product of their interest.

The data available from this classroom contrasts with Hennessy and McCormick's (1994) notion that the inability of students to transfer knowledge from other disciplines such as science and mathematics hinders their ability to design. The students who identified science and mathematics in their luge project critiqued and reflected on their understanding more explicitly than the ones who could not identify science and mathematics. This indicates the transfer of a domain of knowledge which is unique and different from science and mathematics, and focuses on application. The domain of knowledge is unique to the context and relates to technological ways of constructing a product which includes both procedural and conceptual knowledge. Johnson (1997) argued that knowledge does not transfer easily because students may learn how to perform a strategy but they do not learn when it is appropriate to use it. The students from this classroom acquired knowledge appropriate to their design through participating in the classroom community where they experienced how different contexts require reshaping of their prior knowledge (materials, tools, resources and concepts from science or mathematics) and for adjustments to be made to create a usable form of knowledge. This enhanced their ability to transfer the information acquired from one context to usable knowledge in another. According to Sidawi (2007), technology draws from various disciplines which include science, where teaching science and doing technology can be intertwined. The information from science and mathematics was reshaped and reconstructed (Layton, 1991) as a result of the context in which students participated.

Designing in technology provided the opportunity to help students enhance their transfer of knowledge from previous technology sessions, prior knowledge from other classes, and demonstrations and negotiations while designing and making. Johnson (1997), Faraj and Johnson (2011), Griffiths and Guile (2004) have conducted extensive reviews of the literature related to the issue of knowledge transfer in technology. Based on his review, Johnson concluded that knowledge transfer depends on the depth of learning (Perkins & Salomon, 1988, as cited in Johnson) and the familiarity with the context. He explained that deep conceptual understanding of the knowledge would enable the learner to look beneath the surface structure and recognize the abstract rules that apply in other situations. The students from this study developed conceptual understandings as they were able to construct the product whilst critically engaged in technological discourse, and critique their own design using technological concepts and scientific principles. The student reflections about how they design demonstrate the predominance of procedural knowledge, with an element of trial and error, and a natural interaction of science with technology. The information from science was contextualised which led to its transfer during the design and construction phases of the project. It can be said that learning occurs when the understanding of product mechanisms, materials, manipulative techniques and tool related practices is co-constructed during verbal dialogue and then appropriated (Bakhtin, 1981) by the student. This is when the meaning and use of the concept shifts from external design environment to the internal (personal) understanding. The meaning of the conceptual knowledge from science and mathematics was understood by the students within a design context which was relevant and could be recalled when requested since the meaning becomes personal to the student.

This approach enabled the students to understand the scientific principles governing the observable phenomenon and incorporate them in a usable form in their concept drawings, conclusions, component designs and the developing product.

7.5.3 Thinking Involving Science and Mathematics

In a technology classroom with a design project, students think and act in terms of making their product structurally strong and durable which might be the most important design criteria in certain instances. The problem-solving ability of the students in this project enabled them to make design decisions in terms of construction and assembly of the components to make them structurally stable and durable. Students visually inspected the components to check for stability and strength of the product while thinking about various loads and forces being applied on the luge assembly and providing appropriate reinforcements. This highlights a higher level of thinking and the context oriented nature of knowledge. One such example is where students identified the need to check for excessive bending and took appropriate precautions to prevent breakage or collapse of the frames. This structural concept has a component of applied science recognised by some but not by others while designing and making.

Because design is context dependent, Mawson (2003) emphasized the need to give the students time "to immerse themselves in the context of the task" (p. 123) prior to posing their design solutions. As students became familiar with the context of designing the luge, this provided an opportunity for the relevant science and maths concepts to integrate through the acquisition of context relevant technological knowledge allowing the transfer of knowledge. Research has shown that familiarising students with the context increases the range and appropriateness of the solutions the students developed (Video Campus, 2001, as cited by Mawson, 2003). For example, the idea of weight being applied to the frame was a trigger for students to provide reinforcements achieved after the visual inspection of the luge. McCormick (1997) defines this kind of knowledge as 'strategic', as a 'how-to-decide-what-to-do-and-when' knowledge (p. 145). These ideas developed when the students familiarised themselves with the context and started to make the frames and aligned them with the body pans.

Roth (1995) found that the materials that were used to construct technological artefacts served as a dimension of communication that students could utilize until they became familiar with the scientific concepts involved in their designs and were able to discuss them more. The information from science was introduced during the design stages to reinforce the theory with investigation to provide an opportunity for the students to make logical connections with the science content. The findings from this study demonstrate that designing artefacts allow students to participate in the context by taking a role of a designer where science blends naturally. The practical nature of technology affords participation and appropriate use of techniques where science finds its way through its application. The outcome of the approach was that the students were able to reflect on their design ideas in both verbal and non-verbal forms, and so develop a technological discourse which included relevant elements of science. A sociocultural perspective, based on the work of Vygotsky (1896-1934), places the social context at the heart of the learning and communication process. In this study, students use physical, cultural and psychological tools to learn and to regulate their language and activity. In Vygotsky's view, the most important of these tools are the psychological tools (Vygotsky, 1896).

The knowledge from science was not viewed as abstract and detached from its context, but re-contextualized in the design context. The student and teacher practices were determined by the intent of the user/creator (mostly operational and structural principles) with respect to constructing a functional luge where elements from science and mathematics were discussed during investigations or demonstrations. Such an approach towards learning recognizes that "knowledge isn't something we pour from one vessel (a teacher) into another (a student)" (Sorrohan, 1993, p. 48). Instead, knowledge is recognized to be "similar to a set of tools. They can only be fully understood through use, and using them entails both changing the user's view of the world and adopting the belief system of the culture in which they are used" (Brown et al.,1989, p. 33).

The information from science and mathematics informed the technological design context both purposefully and naturally. This demonstrated the integration of abstract knowledge (tool) and its application in technology when students actually get involved in the design process. This study is also referring to conceptual knowledge from science and mathematics as a 'tool'. Brown et al. (1989) argued that "it is quite possible to acquire a tool but to be unable to use it" (p. 33); for example, abstract knowledge completely isolated from a context. Thus, knowing and doing have to be "interlocked and inseparable" (p. 35) for learning to occur. The findings from this study have shown that the students were able to recall (because the information was provided to them) and transfer (during construction) the abstract science and mathematics concepts into usable re-contextualised knowledge. This implies that students should be introduced to abstract knowledge within a context where they can apply it in order for significant learning to take place. Through the activity of design, with its social and physical context, students co-produce knowledge, and the learning is embedded in the activity (Brown et al., 1989). Vygotsky posited that human learning cannot be understood independently from the social and cultural forces that influence individuals, and sociocultural interactions that are critical to learning. Thus if the students were able to recall and refer to the science and mathematics concepts, it can be said that they successfully learned its application during the project. They achieved this through participation and interaction with the various aspects of the design environment where elements of science and mathematics were carefully integrated.

The class conversations about students' artefacts and design decisions represented opportunities for introducing and clarifying scientific ideas and concepts. The students recalled scientific concepts to justify their design decisions, and these justifications naturally became a part of the student discourse. Students who sustained an interest in designing and making a functional product also developed competence in justifying design decisions using technological and scientific language during a communal discourse (Roth, 2000). This discourse was shaped by students' own practices and interactions with the various aspects of the design environment. The co-construction of new knowledge was a result of discourses which incorporated elements of science (concepts and representations) during the various stages of the project. This led to fresh technological and scientific conversations. The use of information from science was possible only because knowledge already existed in its abstract form and was integrated into the luge context. This led to its application as knowledge in technology. Thus, a technological design context provided the teacher and students with many opportunities to use their language, to talk about the science related to wheels, chassis, laminated plywood and steel, and to suggest relevant features of their design. Even during conversations about components and shapes, the basic concepts from science were contextualised, which provided additional occasions to highlight the practical application of science. Also, the presence of a constructed product provided opportunities for deictic and iconic gestures to emerge for introducing contextualised science. This led to its application during construction.

The next section will illustrate and discuss the alignment and misalignment with science that developed within the technological design context.

7.5.4 Conceptions and Misconceptions in Technology

Students were aware of their own thinking in terms of the product and could justify the design decisions they had made and the strategies they had used to produce the desired outcome. Research suggests that metacognitive capabilities develop over time and depend upon a knowledge base (Brown & DeLoache, 1978). For example, without knowledge of the domain of technology including properties of materials and manipulation, students would have difficulty reflecting on their own design decisions. When the students communicated their ideas, they used design language, and they used it to describe their experiences and the concepts they had developed (technological and scientific). They did this through interaction, negotiation, discussions, demonstrations, appropriations and feedback, which together aggregated into more systematic knowledge of developing a product. Students were initially not clear about describing what they knew, but familiarisation with the context led to the improvement of their skills, especially since they had practice in how to think about and discuss their own thinking (Brown et al., 1983). The technological design context encouraged an exchange of ideas, thoughts, knowledge and skills. This was achieved through group discussions, group problem-solving, or reciprocal teaching, and provided opportunities for expressing their thoughts, including their conceptions and their misconceptions. For the purposes of this thesis, the term 'misconceptions' will be used to refer to "ideas that differ from definitions and explanations accepted by scientists" (Schmidt, 1995, p.1).

Students demonstrated the ability to think strategically and to problem-solve, plan, set goals, organize ideas, and evaluate what is known and to seek what is unknown. Many of the ideas, techniques and strategies students developed were through interacting and working with each other in the design environment. During these stages, students' pre-existing ideas and everyday knowledge may have formed 'misconceptions'. Misconception is considered to be the most widely used term in the literature (Hamza & Wickman, 2007) so this term will also be used for this study. Student's misconceptions affect learning and the acquisition of new concepts. The study of misconceptions associated with natural sciences has been part of discussion for a long time (Devereux, 2000).

Technology provides a context where students can draw on their prior knowledge, for example, how objects behave, and they can include using science and mathematics. In this study students developed an understanding from the results of the momentum testing investigation that a heavier person has a slight advantage over a lighter person in terms of speed. Students did mention that the heavier pilot took less time, which contradicts Newton's laws, but an explanation of such a conception can also be derived. The reason for the contradicting data may be explained by the greater push start velocity generated by the heavier pilot than the lighter pilot as this may have added to the time taken to complete the run. Neither the teacher nor the students considered it important at this stage to explain their findings scientifically by considering concept of forces, momentum, principles of conservation of energy or centre of gravity. However, a close analysis of some students' portfolios suggests that such investigations may have provided an opportunity to develop/reinforce or to rectify the misconception students might have developed through the testing. The students observed that the heavier pilots took less time to cover the same distance compared to a lighter pilot. Some also noted that this difference was insignificant, indirectly implying that the weight of the pilot has little effect on the speed. Some students, therefore, developed an understanding from their recorded data that weight is a significant factor affecting the speed of the luge under the effect of gravity. The conclusion drawn by the students is based upon their experimental data, rather than a sound scientific understanding. This understanding was co-constructed by the students during interactions and negotiations while performing their investigations in the design environment. Students may not have considered it essential at this stage to explain the reason behind the observations they had made, or they may have found it difficult to articulate their claims. This seems consistent with findings from Sadler (2004) who claimed that students struggle to provide appropriate scientific evidence and reasoning for their claims, and so misconceptions may arise. In this example, the students concluded that the weight of the pilots significantly affected the speed of the luge, without making any references to science principles, and so developed a misconception.

Students may bring ideas into the classroom which may differ from accepted scientific concepts and theories. Valanides (2000) also refers to these concepts as misconceptions and argues that these may constitute significant obstacles to learning. Even though in technology it is not necessary to explicitly refer to science concepts, technology can serve as a significant platform to address cross-curricular connections. For example, student responses to the rationale for lowering the body pans included reasons such as aerodynamics and stability so the luge could attain higher speeds. Lowering the body pans can lead to a more stable and controlled ride, but reducing aerodynamics is questionable and is a possible misconception. This also indicates that some students' understanding of the concept 'aerodynamics' does not seem consistent with the science principles and they may have confused the actual meaning of the terms.

From Andre and Ding's (1991) point of view, conceptions are ideas that children "have incorporated into their cognitive structures that they use to understand and make predictions about the world" (p. 303). Students from this classroom may have incorporated such conceptions through their own thinking (Russell & Watt, 1992) and through their experiences in the design environment. Hanuscin (2007) noted that misconceptions form in various ways and one person may pass their misconceptions on to others. Cohen and Kagan (1979) and Hanuscin also argue that misconceptions can arise when two or more concepts get mixed up. In this study, students may have confused the meaning of the centre of gravity with aerodynamics concepts and this might have added to their misconception.

Another possible source of misconceptions are common words which are used in every day conversation but do not have the same meaning when used in a science or technical context (Hanuscin, 2007). An example of this could be the confusion students expressed between the terms stability and speed. Students might have conceptualised that a stable ride allows the luge to travel at greater speed. Students might have confused the two concepts of aerodynamics and centre of gravity in the luge context while associating it with speed and stability. Thus, misconceptions can arise from both conceptual confusion and incorrect terminology (Cohen & Kagan, 1979).

A further issue arises when students come into technology classes with conceptions that are used to generate claims without justification, and this may cause misconceptions to arise in the classroom. Research has been carried out which demonstrated that children's comprehension may result from misconceptions or inadequacies in their background knowledge (Eaton, Anderson & Smith, 1984). Students' concepts should not be ignored and should be part of the content of teaching by identifying them and providing opportunities for them to "experience phenomena which run counter to their conceptions for the purpose of inducing conceptual change" (Valanides, 2000, p. 362). The conclusions developed by the students can be made explicit in technology by introducing them to the concepts of science they learn in science classrooms (as the teacher did during momentum testing), even though this is not a goal of technology.

Researching children's misconceptions is crucial since once the concept is secured through practice, it becomes the individual's personal understanding: it makes sense to him or her and the student will retain the information for a longer period of time. Also, the earlier student misconceptions can be detected the better. Work can be done with students to rectify their misconceptions and this, in turn, will help children's scientific learning to progress (Ravanis & Bagakis, 1998). Such an approach might be more sensible if an effort is made towards ensuring that students understand the nature of a product in terms of the underlying science or mathematics. This would be more meaningful for the students as they would be able to see the relevance of the concepts.

During this study the students and the teacher communicated regularly in the technology classroom through one-on-one interactions, group discussion and negotiation to develop a common language and terminology of design. During these discussions, the students had to verbalize and make explicit their design choices which gave rise to scientific and technological discourse. In this technological design context, students examined and justified their practices in detail, using various scientific terminologies, and these will be discussed in the next section.

7.5.5 Discipline Specific Language Developed by the Students

With rapid technological changes taking place around the world, it is likely that specific skills demanded in the future will differ from those required in the past (Cedefop, 2009; Drago-Severson, 2012). Today, these skills include being able to communicate, share, and use information to solve complex, real world problems, in being able to adapt and create solutions in response to new demands and changing circumstances and to command and expand the power of technology to create new usable knowledge (Pacific Policy Research Center, 2010). In technology, demanding explanations and justifications for individual thought and actions rests upon teacher set specifications and the relationship established between the students and the design environment. The development of discipline specific language in a technological design context was observed in this classroom. This occurred through the students' participation in an interactive working environment which included teachers, materials, resources, tools, practices and manipulative techniques.

In the class observed, students seem to be able to adequately express themselves about their design using everyday language which also incorporated scientific terminology. During the study, there was sufficient exposure to basic scientific concepts and language forms, to allow them to be adapted to the learning environment in such a way that they would fit naturally within the design context. The concepts from science and mathematics were introduced by the teacher both orally and in a written form (hand-out). This made the language comprehensible and easy to understand during discussions (van Eerde et al., 2008). The scientific theory and concepts were coupled with practice using language which incorporated both science and technology terminology and provided students with an opportunity to observe the relationship that exists between the two domains.

The terminologies and expressions were learned along with technological practice and through participation in the design context. The need for students to reflect and justify the design actions and decisions created a necessity to also understand the context and to communicate in both verbal and written form. A shared meaning between the students and the teacher was necessary and this occurred by using common words and terminologies with specific meaning. By giving a definition, in this case of the scientific concept, the teacher and students made it clear how they wanted to have the term understood in the context of their study. To mention a few examples, the term 'gravity' was understood by the students as something which 'pulls' the vehicle down. The luge research phase initiated conversations where the term 'streamline' was referred to, and which indirectly indicated the concept of 'aerodynamics'. The discussions and conversations among the teacher and students also demanded the use of scientific terminology such as 'tensile strength', 'centre of gravity', 'force', 'neutral axis, 'radius of curvature', 'pressure' (referring to force) and 'tension and compression'. The familiarity with, understanding and the usage of these terminologies by the teacher is an important aspect in such an environment because students tend to accept what the teacher models. In various sessions the teacher introduced and recalled these terminologies and concepts, and as the students became more familiar with the context, they started to refer to these concepts in their own words, for example 'tensile strength' was referred to as the 'point where it breaks'. The portfolios of some students also incorporated the terms and concepts that were introduced by the teacher (like an explanation of tension and compression) usually in their correct scientific sense.

Students tend to accept terminology provided by the teacher and this leads to the social acceptance of the term. As the dialogue among the students, teacher and the interaction with the design environment proceeds, interpretations are made which are refined by the students in a continual process of learning. For example, the use of the term pressure was introduced by the teacher during a classroom discussion around body actuated steering, tension-compression hand-outs, material testing (plywood and steel) and the hydraulic press demonstration (pressure readings). The use of the term pressure (referring to force or weight) took place in various contexts during the design stage of the project. Scientifically, pressure cannot be classified as a force or a weight, but a product of a force. Even though the meaning behind the term may not have been significant in this context of building a luge, it is interesting to observe the usage and acceptance of the term pressure as a force in the luge context. Another example is from JS's portfolio where the student argues that his luge was able to withstand the 'weight' of the pilot, and incorporated terminologies such as 'stress on the components', 'strong framework', 'speed' and 'weight ratio' to support his design decisions. JS also noted in the student questionnaire that the body pans are placed closer to the ground so there is 'no movement of air underneath to slow the pilot.' This refers to the concept of 'aerodynamics'. It can be said that the student understanding of science ideas was consolidated in an artefact, and they could explicitly justify design decisions and structural logistics using science.

Parkinson (1999) explains how specific words from science can have different everyday meanings. The term energy for example, has a specific, reserved meaning in science [and technology sic]. Yet it has a very unscientific range of applications when, for example, children claim they '…have no energy today!' Similarly, the term applied pressure in this study was incorporated by a few students in their portfolios during the justification of the process of testing and selection. This shows the shared understanding students developed because of the continuous use of the term pressure by the teacher. Also during the focus groups, LG and EM mentioned the term pressure in the context of the lamination of plywood. Even TJ and JC mentioned that the testing of plywood was performed at extreme pressures, either referring to the force applied on the plywood or to the readings on the hydraulic press. The term was utilised in various contexts during the luge design and had various interpretations by the students, the most common being force or weight.

In summary, the communications of students in a technological design context is different to what we may expect in a science or mathematics classroom, because of the nature of technology. In past research conducted in mathematics and science classrooms, the teachers were observed to merely tell the students what a word means. Contextualization and promoting interaction (language production) were mostly absent in these classrooms (Prenger, 2005), even though this cannot be characterised as typical in all science and mathematics classrooms. In a technological context, the participants identify needs, define actions, and identify concepts (technological and scientific). This is achieved through discussions, demonstrations and negotiation which have an effect on the discourse. The commonality in the discourse is achieved thorough cognitive agreement between the teacher and students, and through interaction and familiarity with the context.

In a Zone of Proximal Development (Vygotsky, 1978), understanding is shared and created (Mercer, 1995) and not merely transmitted in the interaction within and between the co-participants of an activity. This process is mediated both by the available cultural tools, such as machines, pen and paper, tools, techniques and electronic media, and by the cultural practices of the group such as the desire to make a functional product. In addition, the extent to which students interact with each other and the aspects of the design environment also impact on this process. The ability to negotiate meaning is particularly important for novice students, such as Year 11 technology students, because they did not come with a shared vocabulary to talk or write about the design decisions and physical phenomena. However, their participation in the context clearly influenced their understanding and vocabulary development.

Not ignoring the position of mathematics in technology, the following section will discuss the perceptions and experience of the students in the application of mathematics to the design context.

7.5.6 Experience and Perceptions of the Students of Mathematics

The major part of the project's focus was on designing and making an artefact where students worked individually, collaborated in groups, and interacted with the aspects of the design environment. Mathematics can be structured into and made explicit to the students during these stages. MY commented that "it is actually fun because you are learning and doing something, but sitting in the maths classroom can get boring at times" (MY, focus group interview). LG further commented that he enjoys technology because it has a practical component where the application of theory takes place. These findings resonate with what Merrill, Custer, Daugherty, Westrick, and Zeng (2008) found in their study that high school students believe that mathematics concepts are better understood when they are connected to solving a problem or building an artefact. Merrill and Comerford (2004) noted, "students will begin to see the 'connections or linchpins' that connect different fields of learning" (p. 10) through a more integrated approach. In this study the connection between mathematics and technology was predicted by the students in the earlier stages of the project, indicating that the students participated in the technology classroom expecting mathematical operations to be employed during the design and make stages.

The technological process of making the product exposed students to real scenarios requiring the mathematical application of concepts and operations. It is interesting to note the position of mathematics (of application) in technology and how students develop a practical understanding of mathematical operations through participation in a technological design context. The findings from this study also confirm those of previous studies about pupils' difficulties in understanding and applying various mathematical concepts and operations in a design context. The design context provided an opportunity for the students to apply mathematics, which was a challenging experience for many. The students were able to transfer basic mathematical skills and grappled with the embedded mathematics they encountered in different contexts. Drawing parallel lines embedded in an orthographic projection of product components and checking for symmetry of the components become something distinct from those seen in traditional mathematics lessons. Mathematics found its application within a real context where there is no correct answer, but calculations had to be carefully carried out to make a customised product. The context led to even more embedding of mathematics concepts, such as the use of angle in 3-D drawing (geometry in concept diagrams and cardboard patterns), and an instance where the teacher integrated the knowledge of processing and some basic mathematics in terms of drawing circles of known radius with a compass to cut a rectangular section off the frame (for student HM). At such times, the students were unable to draw upon knowledge from their mathematics lessons. Similar results regarding transfer of knowledge between contexts have been found by Norton and Ritchie (2009). Empirical studies also show that there is a difference in the classroom culture of mathematics and technology students. This relates to the use of language, procedures and concepts, and represents obstacles for students in applying their knowledge of mathematics in technology and design activities (McCormick & Evans, 1998). The integration of mathematics was evident but students were confronted with various challenges during the application of this in the technological design context.

The application and transfer of basic mathematical skills such as addition, subtraction, division, multiplication and working with decimals was extensive in the design context; however, some students were frustrated as they grappled with the embedded mathematics. For example, students were frustrated with their rectangular steel trucks as they required extensive filing and cutting, and this took considerable time to fit to precise measurements as specified by the orthographic sheet. The measurements and calculations were significant as the truck plates had to be customised for the 70mm diameter wheel sets. Some students became frustrated by the exact precision and measurement demanded by the task and the teacher's attempt to set the standards high. The students expressed their frustrations in very explicit terms during interviews, and some students refused to deal with the precision (calculations and measurements) demanded by the task towards the end. NT and JS found the application of mathematics in technology 'boring,' especially when they had to construct the truck plates with precise measurements. This was an instance where students became frustrated with the excessive mathematical calculations. Even classroom observations and informal conversations in Stage 2 illustrated that the students found the tool related manipulative techniques used in shaping the body pans such as sanding and sawing, along with the applied mathematical measurements, slightly overwhelming. The process of tracing the cardboard pattern onto the plywood involved drawing lines of symmetry with appropriate measurements was also problematic for some students in Stage 2 as recorded by the students in the questionnaires.

The general mathematical operations and basic concepts did not seem to be problematic for every student during the design and make stages of the project. The experience of applying basic mathematics to the project was positively acknowledged by some students. For example, students MY and EM found the application of mathematics relevant and helpful during the design and construction phases. The students found mathematics to be their weak subject in traditional classrooms but enjoyed its application in technology. Students became aware that the mathematics required in the luge context was quite basic and could be applied without significant issues. MQ and TG commented that the mathematical calculations were straightforward and belonged to a lower academic level than what they were learning in current mathematics lessons. Individual designs incorporated mathematical calculations to varying degrees and students found it slightly tedious to apply them during the construction phases of the project. However, after the completion of the project, all the students recognised and appreciated the mathematical principles and operations utilised in the design context and disregarded the difficulty they faced while applying them during construction. For example, students (MY and EM) found the application of mathematics relevant and helpful during the designing and construction phases. The students found mathematics to be their 'weak' subject in traditional classrooms but enjoyed its application in technology during the focus group interviews.

The advanced mathematical concepts and operations were identified to be problematic and students were not able to apply the concepts swiftly in the design context. In attempting to account for the need to discuss the weight distribution procedure, essential discussion without demonstration of the procedure was carried out in the design room. The teacher verbally explained the procedure and demonstrated the mathematical rules of calculating ratios and percentages to locate the position of the truck plates. The concepts already identified as problematic such as ratios (e.g., Lamon, 1995) and percentages, were challenging for the students to apply in the workshops. The teacher could have adopted alternative representations or demonstrated the procedure to accompany the concrete mathematical concepts in order to facilitate the student's application. The researcher's observational field notes indicated the tension students felt in applying the procedure and the mathematical calculations involved. In catering to the needs of different students, the teacher was not aware of the problematic mathematical concepts and the necessity for students' prerequisite knowledge to provide the level of scaffolding that they needed in order to engage in procedures which incorporate mathematical operations. This is significant in technology since the aim is making a customised functional product and mathematics is necessary in these practical tasks.

Even though the requirements of the luge task were clearly set by the teacher during the weight distribution process through discussions, further demonstration and scaffolding of the procedure could have been incorporated. Technological mediated activities incorporating considerable mathematical calculations can be daunting for the students if timely support and scaffolding is not provided. The weight distribution stage provided an opportunity for students to be disengaged from the task because the procedure was not practically demonstrated to the students. The mathematical calculations involved in the procedure might also have demotivated many students from attempting the process by themselves. The students followed the instructions provided by the teacher in the design room but requested that the researcher intervene and take them through the procedure and the mathematical calculations. They may have demonstrated competency in the attributes of ratios and percentages in their mathematics class in traditional settings, but failed to do so in technology. In this regard their mathematical knowledge might be described as instrumental (Skemp, 1978). The students' abilities to apply the knowledge they had learned in traditional classrooms to unfamiliar contexts was seen to be limited. This does not imply that the students could not do basic mathematical calculations such as scales, addition, multiplication and division, but there is strong evidence that procedures involving higher order mathematical concepts and principles could not be applied with ease. The pedagogical approach that the teacher adopted was traditional, without scaffolding and student participation, and had many of the elements of instructivism (Marsh, 2004). This included verbal instruction at the beginning of the session in relation to key mathematical concepts and the expected outcome of the procedure. The teacher may have assumed that students had a greater level of understanding and capability and were able to carry out the procedures and calculations by themselves.

Having discussed the various factors that assisted and hindered the integration of science and mathematics in a design context, the next section will highlight and discuss the preferences of the students as to when such integration of cross-disciplinary knowledge should happen in technology.

7.6 Preferences on Integrating Cross-Disciplinary Knowledge in Technology

The integration of knowledge from science and mathematics in technology can be a frustrating experience for the teacher. While it can align well with the procedures followed in technology, its integration should be carried out carefully and with a purpose. In this study the information on tension and compression was discussed for a number of weeks during and after the material testing phase. After the material testing was carried out in the workshop, the teacher again discussed and explained the content from the hand-out to the students in the design room. Towards the end of the theoretical session, it was observed by the teacher and the researcher that there was some disinterest and motivational loss among the students. The data from the student questionnaire introduced towards the end of Stage 1 indicates that the students have preferences as to when cross-disciplinary knowledge should be integrated in technology and this will be discussed in the following paragraphs. The perception and attitudes of the students towards the integration of information will also be discussed and this will provide some direction towards supporting an integrated learning environment.

The students appreciated that the information from tension and compression was integrated before and during the material testing stage of the project. Students prefer to know the information from science before they start any technological investigation, and also appreciate referring to the information during the physical testing of the materials. This was obvious from the data collected from the student questionnaires where they indicated that the information led to better understanding. For example, LG, MY and EM appreciated the practical use of the knowledge in the context of luge design. The students could make sense of the information when they practically observed the phenomenon and this helped in affixing meaning to the investigation. TG, JC and MY mentioned during the interviews that the information on tension and compression was significant within the practical domain of testing materials. Other students mentioned that the knowledge should not be integrated in its deeper contextual meaning, implying they intend to know just the basics that might be useful for them when designing in technology. Students indicated that they had no intention to perform a detailed analysis of the phenomenon they observe using science principles. JS mentioned that such knowledge made it easier to understand the scientific reason for the material testing in technology. ST and JP agreed that it is good to know such information in general even though they might not be using it in the context of luge design. The significance of such knowledge was identified by almost all the students in questionnaires and during the focus group interviews. However, the level of such knowledge should be carefully selected as it can affect the motivational level of the students in a technology classroom.

To enable teachers to provide an integrated teaching and learning environment, Zemelman, Daniels, and Hyde (2005) have arrived at the following research-based list of "best practices" for teaching mathematics and science: (a) use manipulatives/hands-on (make learning concrete and active); (b) use cooperative group work; (c) use discussion and inquiry; (d) use questioning and making conjectures; (e) use justification of thinking; (f) use writing for thinking, feelings, and problem solving; (g) use a problem-solving approach to instruction, making content integration a part of instruction; (h) use technologies such as calculators and personal computers; (i) promote the role of the teacher to that of a facilitator of learning; and (j) use assessment as a part of instruction.

It can be said that the context of technological design provides for the implementation of many of the above emphasized best practices in a technology design context. Students can benefit from observing an example of reasoning that clearly includes a scientific principle to show why the evidence supports the claims (Conezio & French, 2002). As noted above, the hands-on learning context of doing technology is an area where science and mathematics can be integrated. This notion has implications for technology classrooms if educators wish to enact an integrative learning environment.

7.7 Summary of Chapter

Technology provides an opportunity for the students to work towards achieving an optimal solution to a problem or need. The practical nature of technology makes it possible to purposefully integrate abstract knowledge from science and mathematics to inform the design context. Some students were not aware of their application of cross-disciplinary knowledge while making a product, but they could later recall the science concepts. There was evidence from the classroom that students worked as problem solvers who applied the information from science and mathematics logically to new situations while designing and making. In particular, the students in this study learned to develop a product through manipulating materials, and through technological discourse which included elements from science and mathematics.

CHAPTER 8 CONCLUSIONS AND IMPLICATIONS

8.1 Introduction

This chapter builds on the discussion to reach conclusions and identify implications with their recommendations for technology teachers, STEM educators, science and mathematics teachers, and for researchers in the field of technology education. This study aimed to investigate the classroom practices of a teacher and students from a school in Hamilton, New Zealand, to study the integration of science, mathematics and technology in a technological design context, so it is anticipated that there may be applications to other STEM areas.

The next section will present the conclusions derived from the findings of this study regarding the integration of science and mathematics in a design context of making products.

8.2 Conclusions

The integration of science, mathematics and technology in a technological design context happens both naturally and purposefully; this study has revealed instances where integration has been effective and meaningful for the students and instances which hindered integration from happening in the technology classroom. The students and teacher in this classroom interacted with each other and the design environment through the use of culturally specific artefacts, tools (including psychological tools) and materials which resulted in the formulation of contextual technological knowledge which incorporated elements of science and mathematics. With regard to the integration of science, mathematics and technology, the study arrives at twelve conclusions which are discussed in the following paragraphs.

1. The focus of students in this study is the development of generic skills through the design process, not to learn science and mathematics. The students understood at the very beginning of the project that they would acquire skills and knowledge as they went through the technological process of designing a product. The focus on acquiring knowledge of materials, manipulative techniques, tool related practices, mechanisms and operational principles dominated during the design and construction phases of the

project. This led to the co-construction of contextual knowledge which represented the student's epistemology of technology (Norström, 2011). Technological knowledge is contextual and is appropriated through practice and participation of the students within the classroom community with the intent of developing and improving a product and not to learn and apply science and mathematical concepts.

2. Discussions amongst the teacher and students facilitated the integration of scientific and mathematical knowledge into technology. It was through discussions focused around the why aspects of the procedures which initiated consideration of information from science and mathematics. The information from science was integrated with the practices of technology to understand why certain structures work in a particular fashion and this knowledge base was carefully established by the teacher. The process of designing initiates interaction among the students and their surroundings which leads to the construction of integrated contextual knowledge.

3. The participation of the teacher and students in discussions, generated around understanding the data and information collected through experiments, resulted in written conclusions which integrated information based upon science and mathematics principles. The requirements set by the teacher forced the students to communicate their findings and design decisions which stimulated technological discourse and incorporated abstract scientific terms and mathematical concepts. The teacher's use of scientific principles and terminology during the design process was prominent, and student discourse developed to include the terminology. The intent of the teacher was also to provide students an opportunity to make sense of the investigations and procedures so the students could apply the theory to their design and construction decisions.

4. The teacher's use of scientific terminology during technological activities led to the acknowledgement and acceptance of the terms by the students within the context. The students made use of the scientific terminology to justify design decisions. The use of terms and terminologies by the students

were simple to comprehend by the teacher and were contextualised. Students tended to accept the terminology repeatedly used by the teacher. Students could communicate their design ideas through a language which did not separate science and mathematics from technology. In this classroom, the communications of students in the technological design context were relevant, realistic, intelligible, contextual and technological in nature since their discourse had elements of science and mathematics integrated with their design decisions.

5. Students brought a broad range of knowledge from their prior experience to apply to their technological design decisions. It was important to identify this knowledge for two reasons: firstly, so it can be built upon by the teacher in the construction of new knowledge, and secondly, the knowledge may be flawed or represent misconceptions which need to be addressed. This study found that the students had prior technological and scientific knowledge which influenced the development of new technological knowledge. The stage when early conceptions of the students can be identified through discussions or during investigations has been identified as crucial in order for these ideas to be exposed and subjected to further development. This study revealed a tendency for the students to develop misconceptions collectively due to the fund of knowledge each student brings to their technology class.

6. It was found in this study that students worked in the technology classroom without realising that they were applying scientific principles during their design and construction activities. Student experiences can be guided for science learning to take place by being explicit about the instances where integration of science and technology takes place through technology. Some students from this class could not recognize any connections between science and their technological practice, even though in their practice, the links were there. This indicates how the tacit and procedural knowledge of technology encompasses conceptual knowledge from science, though it may not be realised. The scientific principles associated with the shape and

functionality of their project components might remain implicit for the students, but an understanding of the mechanisms and operational principles is developed during the construction process and could be productively utilised for science or maths learning to happen. Students experimented and investigated to solve emerging problems during the process of design, and these experimentations had an implicit component of science application. The students were unaware of this natural integration of knowledge from science or mathematics during their practice.

7. It was found that an emphasis on design and construction, by making references to materials, construction techniques and constructed products, assisted the students to construct a functional product, but hindered the integration of science, mathematics and technology. The emphasis was on procedural knowledge considered to be primary to construct the functional product. Students from this classroom were interested in understanding and exploring advanced technological ways to achieve better project performance. Their over reliance on existing technologies and acquiring knowledge on processing materials through various manipulative techniques might have diminished or made implicit the component of science underlying the physical phenomenon.

8. Students identified the application of mathematics during the initial stages of the project, which indicates their understanding that knowledge from mathematics formed an integral part of their technological designing. The practical nature of technology naturally created an environment for the application of basic mathematical operations and calculations. Students utilised basic mathematical knowledge learned in previous years, and as the design progressed, they applied this knowledge to their practice. The use of mathematics was as a tool to tabulate results, calculate averages, draw geometrical shapes and to check for lines of symmetry while cutting and manipulating materials.

9. The majority of the students from this class found it difficult to apply ratio and proportion calculations to their design without facilitation and scaffolding. The teacher was not cognisant of the problematic areas of mathematics application and so did not provide necessary support. Only one student from this study had explicitly demonstrated the use of mathematics in the design context which can be said to be of higher order (the example of the use of circumference formula for the head rest). The isolated example from one student does demonstrate the potential for higher order mathematics knowledge transfer, but cannot be generalised to the whole class.

10. The purposeful integration by the teacher of knowledge from science is most effectively done when the students can see its direct practical application to the context they are working in. Students also mentioned that if purposeful integration is to be enacted in the classroom, then they need to be familiar with the information before they apply it to any context. Students mentioned that information presented just before or during practical experimentations is sensible as it demonstrates the application of the knowledge.

11. Students could become disinterested if the focus of the teacher shifts towards teaching abstract conceptual knowledge from science during the design stages. This happened when an attempt was made by the teacher to repeat the same contextual scientific concept over a number of weeks. The level of knowledge to be integrated and its period of exposure should be carefully considered, as it can affect the motivational level of the students in a technology classroom.

12. The attitude of the students towards a task or an activity in technology is influenced by the technological procedures and mathematical calculations associated with the task. The mathematical calculations involved with various technological procedures should be carefully presented. In this class, a fair number of students were frustrated by the precision demanded by some tasks and the teacher’s attempt to set the standards high. The expectations set by the teacher in terms of the required precision and accuracy demanded

skills and patience from the students to produce results. Setting high standards like this in technology can lead to demotivation towards the activity if appropriate guidance is not provided to the students during teaching.

These conclusions have implications for STEM advocates and technology teachers because they demonstrate that there are considerable opportunities offered by technology to promote or hinder the integration of science and mathematics. The following sections will discuss the implications for various educators who might benefit from the findings of this interpretive study.

8.3 Implications and Recommendations for Technology and STEM Teachers

There are various implications of this study in relation to viewing technology as a means to foster integrated learning. This study has provided answers to many questions with which the researcher commenced this study like:

- how the nature of technology best engages students in a meaningful learning environment by developing technological knowledge with integrated elements of science and mathematics;
- how the teacher taught and students learnt in technology;
- how the integration of science, mathematics and technology appears to occur in the classroom where the intent of the teacher and the students was to develop a technological product; and
- the aspect of the learning environment which shapes the thinking of the teacher and students leading to the development of a co-constructed version of knowledge.

This study has furthered the understanding of the nature of technology, the practices of the teacher and the intent of the students in relation to the development of a functional product and the integration of science and mathematics within the design context. Due to the qualitative nature of this study, participant samples were small and it is, therefore, not possible to make generalisations about integration of science, mathematics and technology in a design context other than in this study. However, teachers and educators will be able to see the relevance of the findings by making links to their own experience and practice. The following implications can be made for technology and STEM educators who wish to enact an integrative learning environment in their classrooms.

1. The intention of a technology teacher is to facilitate students in designing and making a product which leads to the development of the knowledge domain unique to technology. This unique domain of technological knowledge acquired through their participation in an authentic context can then be used to make explicit the integration of knowledge from science and mathematics. The findings suggest that if students are provided enough opportunities to work on design projects which employ considerable designing, planning and construction, they will develop the generic skills and technological knowledge required to construct the product. The design process presents various opportunities to integrate science, mathematics and technology both The integration of science, mathematics and technology is promoted if the purpose naturally or intentionally which might require the teacher to be aware of the cross-disciplinary links to make the transition from practice to theory (or vice versa) smooth for the students.
    - So, this study recommends that, through the design process, technology teachers provide opportunities for students to construct technological knowledge which is beneficial in attaining an integrative learning environment.

2. This study suggests that discussions initiated by the teacher be directed towards technological practice (in this case the structural assembly and the strength of materials), as this kind of knowledge is unique to technology and provides the context for elements of science and mathematics. It is the initiative to develop a knowledge of the 'product' through interactions with materials, tools, resources and knowledgeable others which leads to the co-construction and integration of knowledge.
    - So, this study recommends providing students with extended opportunities to discuss work and ideas and to communicate with more competent peers to receive support. Such opportunities

facilitate integration of science and mathematics through the quest of developing the usable technological knowledge.

3. This study suggests that a strong focus on the essential procedural knowledge is necessary in technology and to a large extent it tends to surpass any direct dependence on science and mathematics to design. Rather than the science and mathematics underlying the procedures, the procedural knowledge is essential in technology to move forward. This implication is important since an emphasis on suitable materials, construction techniques and already constructed products keeps the intention of the teacher and students directed towards the technological outcome of making the product somewhat isolated from the underlying science or mathematics.
    - So, this study recommends specific instances be identified by the teacher where the knowledge from science or mathematics can be integrated and lead to a better understanding of the physical phenomenon. This approach could also lead to the transfer of knowledge in different contexts where students could logically apply science and mathematics to make design decisions.

4. This study suggests that teachers could consider that students utilise information from science to strengthen their design decisions and conclusions.
    - This study recommends that teachers encourage students to brainstorm their initial ideas so as to provide opportunities to use information from science or mathematics which can then lead to design decisions informed by a multi-disciplinary approach. The teacher's expectation that students communicate the design decisions through discussions, demonstrations and in writing is a crucial approach towards integration. The teacher might consider requiring students to communicate findings and design decisions developed through participation, negotiation and explanation as this would serve to simulate technological discourse which can help students recall and incorporate abstract scientific terms and mathematical concepts in a contextualised form.

- This study recommends that the introduction of scientific principles and terminology at specific times will help enable students in identifying, recalling and using scientific principles and terminology.

5. This study suggests it would be beneficial for students to be provided with personally meaningful and authentic contexts which allow them to develop research skills such as identifying key variables, interpreting data, hypothesizing, defining and experimenting through the design process. Such a design environment can help students identify the variables affecting the performance of a product leading to the construction of knowledge specific to the context which could be carefully presented to the students to show the integration of science, mathematics and technology.
    - The development of research skills through the design process is recommended since it incorporates the acquisition of technological knowledge which has implicit components of science and explicit mathematics.

6. Students tend to design and construct in a technology classroom without explicitly prioritising science or mathematics, as found in this study. The implication here is that classroom discussions could be carried out with a focus on understanding the application of science and mathematics in the design context as a way of pointing out its application. This focus can be beneficial to student learning by indicating the relevance of science and mathematics. Science and mathematics have a role in devising and shaping technology.
    - Hence this study recommends teachers be explicit about the connections. This can occur during the initial stages of the project to make the students realise the contextualised shape science or mathematics takes in technology.

7. The findings from this study have shown that students were able to make connections and apply conceptual knowledge from science which was provided to them at an earlier stage. This suggests that information from

science and mathematics can be introduced during the project when students can see its relevance, which can then promote the transfer of knowledge (both technological and scientific) to applicable contexts.

- Hence this study recommends that information from science and mathematics be provided before and during a particular intervention with an emphasis on demonstrating how the theoretical conceptual information from science or mathematics finds its practical application.

8. Design contexts and experiences should be crafted in constructive ways to introduce the implicit science or mathematics, since the students do not always recognize the application of the principles of science and mathematics while they design and make in a technology classroom. The design context provides a natural platform to recognise and apply science and mathematics in technology.
   - Thus this study recommends the acquisition of the technological knowledge specific to the context as a primary approach to attain the desired technological outcome.

9. Student’s prior knowledge and conceptions from science and mathematics (related to the context) should be carefully considered in order to avoid the tendency to develop misconceptions. Student’s common ideas and concepts should be a part of the teacher’s interest. If collective misconceptions could be identified early then they can be rectified.
   - Thus this study recommends that teachers include discussions at suitable stages where integration could be carried out. This approach could open up possibilities to understand the conception of the students which could then be acted on for further clarification or improvements. A collaboration with the science and maths teachers would be ideal to identify students current and prior knowledge.

10. With regards to mathematics, students should be provided with technological design contexts which naturally afford authentic and relevant opportunities for handling data through mathematical operations and

principles. The students could identify the use of mathematics even during the initial stages of the project which would indicate that students accept that that mathematical operations and calculations find their application in a technological design context.

- This study recommends that the teacher identifies the application of mathematics by the students during design and make stages and should be well prepared to facilitate students applying the basic mathematics which they learn in their mathematics curriculum. The technology teacher can also encourage students to initiate discussions with their maths teachers regarding the clarification of any mathematics concept and application while designing. This would require an early identification of the maths concepts by the teacher and involving the mathematics teacher with the design project at suitable stages.

11. Practical procedures involving mathematical calculations have to be taught using alternative representations to classroom mathematics or using detailed demonstrations. Alternative approaches should be utilised which might avoid student frustration arising from the application of extensive mathematical calculations. The teacher should be aware of the problematic mathematical concepts and students' perquisite knowledge so he/she could provide the necessary facilitation to the students. Again, assistance in such situations can also arise from more capable students through student-student collaboration in the classroom which could be encouraged.

    - This study recommends that group work be encouraged where there is a mix of expertise available in the classroom. If viable, mathematics and science teachers could contribute to design activities in technology by developing activities or information which supports the design context and provides support for technology activity.

12. There should be provisions for students to reflect on their technological design ideas and decisions by considering external constraints to develop justifying arguments, as such an approach encourages students to consider

information (science or mathematics) relevant to the context. This requires the teacher to be aware of the cross-disciplinary information and knowledge that could be integrated during the design process. Ideally, the teacher should have an understanding of science and mathematics knowledge within the design context. Engaging students in the context and initiating discussions to indicate the relevance of science and mathematics can help students to appreciate the relevance of science and mathematics.

- This study recommends that teachers identify information from science and mathematics which could be relevant to the design context. Information which could enhance the design can be strategically presented by the teacher through demonstration or practical techniques which could initiate critical thinking. Students should be provided information at the right instances ensuring the information is easily comprehensible and understandable by the students.

13. Theoretical sessions involving science concepts or mathematical calculations should be carried out with sufficient scaffolding from the teacher in order to retain student engagement in technology. Such scaffolding might include practical demonstration of the procedure to the whole class and assisting students with the mathematical calculations.
    - It is recommended that the teacher plans such procedures in advance so necessary steps can be taken to facilitate the demonstration of such procedures for student learning and integration of science or mathematics.

This research has studied the generation of co-constructed and contextualised knowledge in a technological design context through analysis of the practices of a teacher and students in a technology classroom. The findings from this study highlight how students integrate science, mathematics and technology. These implications and recommendations may assist technology educators who wish to create an integrative learning environment where students appreciate the relevance of science and mathematics to technology. The next section will discuss implications for further research to contribute to the field of technology education, STEM education and integrative learning.

8.6 Implications for Further Research

The findings of this study support evidence that the epistemology of technology had remained ill-defined (Kroes, 2012; Medway, 1992; McCormick, 1997; Norström, 2011). The technological knowledge students develop is contextual and localised in nature, and elements of it cannot readily be distinguished as science or mathematics. The procedural and conceptual knowledge of technology has implicit elements of science and mathematics which could be made explicit during designing in order to provide reasonable explanations for the design decisions. Technological knowledge is multifaceted and includes information about technological artefacts and mechanisms with operational principles as well as skills necessary to perform technological work. The application of conceptual knowledge from science and mathematics to technology, and the tacit knowledge of students has been the subject of this study, and has indicated how students integrate science, mathematics and technology in a design context. Technological knowledge is vast and cannot be universally defined. Not all technological knowledge be easily demarcated into science and mathematics, but the interaction of science and mathematics with technology has been discussed in this study. To gain a deeper understanding of integration of science, mathematics and technology in a technological design context the following recommendations for further study are made.

a) A study similar to this present study should be carried out that would involve a larger sample of students and teachers (technology, science and mathematics) in order to provide more comprehensive insights into the interaction of science, mathematics and technology from the teacher's and students' perspective along with the professional learning needs of the teachers to create an integrative learning environment. Also, a larger-scale study would facilitate more generalizability of the findings in the field of technology and strategies to facilitate the integration of science, mathematics and technology.
b) A longer term study is recommended in order to evaluate the impact of an integrated learning environment involving science and maths teachers on

student's motivation and academic achievements in science and mathematics. Such a study would also provide evidence of whether or not science and mathematics teachers' participation in technology has a positive impact on students' learning outcomes technologically, scientifically and mathematically.

c) This study opens up an opportunity for researchers to further investigate student's abilities to transfer knowledge from domains of science and mathematics to technology. The study also identifies a discrepancy between the data and literature (Moreland & Jones, 2000) about student's inability to recall and apply knowledge and student's ability to transfer knowledge from other disciplines to technology without explicit prompting. Their study revealed that, in fact, students had difficulty with knowledge transfer unless explicitly taught by teachers. In this study, students were able to recall knowledge from science, mathematics and technology both with and without prompts from the teacher.

d) Another potential area of further research is to study student discourse in the context of integrative interventions to identify the degree of alignment and misalignment with scientific knowledge. The interaction with the product and the aspect of an integrative design environment can lead to formulation of conceptions by students which naturally become a domain of their technological knowledge since they rely on field observations, experiments, common knowledge and investigations. It could be useful to assess and rectify any conceptions students bring in technology, or form when they do technology, since the practice can open possibilities to integrate conceptual information from science or mathematics.

e) Another potential area of further research would be in secondary schools where student engagement within a collaborative technological practice can be studied. In this study, when working collaboratively, students were forced to use dialogue with their peers in order to reach a compromise when different design ideas and suggestions were put forward. There is potential for further study into student discourses once students are familiar with the context and scientific principles since their participation within the context has been shown to influence student discourses.

The section above has given some indication of potential areas for research in the field of technology education.

8.7 Answers to the Research Questions

The findings from this study have assisted the researcher to answer the following research questions with substantial data.

1. How does a technological design context of making and designing a product influence the thinking and practices of the teacher and the students in terms of integration?

The discussion that took place in the technological design context of making and designing a product influenced the integrative thinking and practices of the teacher and the students as they made informed technological design decisions through continuous participation and collaboration. The context of designing and making a product provided the students with an opportunity to develop generic skills and to apply information from science, mathematics and technology, both knowingly and unknowingly, to their designs.

Discussions amongst the teacher and students facilitated the integration of scientific and mathematical knowledge into technology. The discussions focused around the 'why' aspects of the procedures which initiated the recall of information from science and mathematics. The technological design context determined the relevant information from science and mathematics which was integrated with the practices of technology. Students brought a broad range of knowledge from their prior experience and applied it to their technological design decisions. Student's prior technological and scientific knowledge influenced the development of new technological knowledge in this context.

The scientific principles associated with the design project remained implicit for the students initially, but an understanding of the mechanisms and operational principles was developed through students' continuous participation, resulting in science learning. This strategy was adopted by the teacher which was acknowledged and accepted by many students.

The practical nature of technology naturally created an environment for the application of basic mathematical operations and calculations. Students utilised basic mathematical knowledge learned in previous years, and as the design progressed, they applied the mathematical knowledge. The scientific principles or mathematical calculations involved with various technological procedures were carefully presented by the teacher at the right times for integration to happen in technology. It was important for the teacher to present the science and maths ideas at the time the students needed the information in order to progress with their designs, so there was an immediacy of application.

The design activities initiated interaction among the teacher, students and the design environment which led to the co-construction of integrated knowledge. The focus of students was to get the project done and to develop generic skills like collaboration, communication, creativity, critical thinking, information technology, numeracy, problem solving, self-management and research skills for independent and life-long learning through the design process. Students came with an intention to design and make a product and information from science and mathematics was not important to them before they started designing. The focus on acquiring knowledge of materials, manipulative techniques, tool related practices, mechanisms and operational principles dominated the design and construction phases. The teacher and students tended to rely only on materials and the manipulative techniques (during construction phases) to acquire the procedural knowledge required for construction of the product.

The participation of the teacher and students in discussions, generated around understanding the data and information collected through experiments, resulted in the integration of information from science and mathematics. The design decisions made by students through discussion and experimentation integrated science, mathematics and technology. Students communicated their findings and design decisions through written justifications and conclusions incorporating science and mathematics.

Students came to technology with a view of designing and making a product but also realised they would be applying mathematics as their design progressed. Students applied mathematics as the design progressed and met with practical challenges. The practical nature of technology created an environment for the application of basic mathematical operations and calculations. Technological procedures which incorporated extensive mathematical calculations affected the motivation and attitudes of some students towards the task or an activity of the design stage as students provided negative feedback. The students tended to become demotivated when they had to apply extensive mathematical calculations to the design work.

2. How did the teacher and the students acknowledge their own thinking with regards to the transfer of science and maths knowledge to technology?

Some students worked in this technology classroom without realising that they are applying scientific principles during design and construction activities. The teacher in this class utilised students' prior experience and knowledge for developing new technological knowledge and by being explicit at certain stages of the product development about the integration of science and technology. The tacit and procedural knowledge of technology encompassed conceptual knowledge from science, though it was not realised by the students during practice. The introduction of the right information from science and mathematics led to the transfer of knowledge to a different context through its application.

The teacher's use of scientific terminology during technological activities led to the use of these terms by the students. The use of scientific principles and terminology by the teacher during the design process was strategically done, so the students understood and learned to use the terminologies and developed their technological discourse incorporating science and mathematics. This demonstrated effective knowledge transfer. Students communicated their design ideas through a language which did not separate science and mathematics from technology, and they made their design justifications relevant, realistic, intelligible, contextual and technological in nature.

The purposeful integration of cross-disciplinary knowledge by the teacher was most effectively done when the students could see its direct practical application to the design they were working on. Purposeful integration was enacted in the classroom, by making students familiar with the information when they needed to apply it to a context. The teacher made sure that the information was presented before, during and after the practical manipulative experimentations were performed in the workshop and the students found the information sensible and easy to comprehend. Students become distracted and disinterested when the focus of the teacher shifted towards teaching abstract conceptual knowledge separated from its context, which occurred at times during the design stages.

Students brought a broad range of knowledge from their prior experience to apply to their technological design activities and made logical design decisions. Prior knowledge was transferred to form new conceptions in technology. Some of the conceptions developed by students within the design context were flawed or represented misconceptions which were not addressed by the teacher. This might be significant in STEM classrooms since misconceptions associated with science or mathematics could be addressed which can reshape the misconceptions and flawed design decisions.

The practical nature of technology created an environment for the application of basic mathematical operations and calculations. Students utilised basic mathematical knowledge learned in previous years, and they applied it during the design and construction stages. The scientific principles involved in technological procedures and investigations were carefully presented by the teacher at the right time for the students to observe their practical relevance. Mathematical calculations associated with the technological procedures were not strategically presented or taught upfront since the calculations were correctly considered basic by the teacher. The students were able to recall basic mathematical calculation techniques and apply them successfully to the design context.

8.8 Concluding Remarks

This study provides a focus on what actually happens in a senior secondary technology classroom: how teachers teach and how students design and make, which has led to conclusions based on the evidence. The integration of science and mathematics within a technological design can be beneficial for the students in terms of gaining generic skills and integrated contextual knowledge through participation. The design process provides extended opportunities for students to understand the product and its operation where integration of science, mathematics and technology remains implicit and can be made explicit in an integrative learning environment. The discussions initiated by the teacher were directed towards understanding the structural assembly and the strength of materials (technological theory), since this domain of knowledge is unique and it remains contextualised. Contextual knowledge in technology can be utilised to make explicit the elements of science and mathematics. Encouraging students to utilise information from science and mathematics to strengthen their design decisions and conclusions can initiate integration of knowledge from science and mathematics. Design contexts in secondary schools and experiences should be crafted in constructive ways for students to integrate science and mathematics, and their prior knowledge and conceptions should be carefully considered.

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APPENDIX A

Permission Letters and Information Sheet for Research Participants

Information Letter for the School Principal seeking permission for the teacher and students to participate in the Research Study

Date: Feb 2013

Dear Principal of the xxxx xxxxx,

I am writing to seek your permission to work with Mr. xxxxxx (Technology Teacher) in a research study for my PhD at the University of Waikato, New Zealand. This study is about observing how students integrate science, mathematics and technology in a technological design context in a technology classroom. This research will look into how students construct knowledge and make appropriate links among science, mathematics and technology when solving a real life problem. This research hopes to achieve a theoretical model that could be implemented in future technology classrooms, to create interdisciplinary and innovative thinkers who can bring in knowledge from various disciplines to solve design challenges of the twenty-first century.

I will be conducting short interviews with the students and the teacher. These interviews will focus on to identify any previous knowledge from science, mathematics and technology used by the students to construct their design. Group Discussions with students will focus on their perceptions and thoughts about the whole process of linking science, mathematics and technology in the classroom.

Data collected during the study may be used in writing reports, publications or in presentations. We will not use your name, the name of your school or the names of other participants in any publications or presentations. We will make sure that we store all the information we gather securely.

I would appreciate your consent to carry this research at xxxxxx. If you need any more details about the project, or issues arise for you during the project, please contact me at tm137@waikato.ac.nz or phone number 021492570. If I am unable to resolve your concerns, you may contact my research supervisors as follows:

Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Phone: 0 7 838 4769

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Phone: 078384466

Yours sincerely

Tiju Mathew Thomas

PhD Student

University of Waikato

Ph: 021492570

Research Consent Form (Principal)

I have read the attached letter of information.

I understand that:

1. The students and teacher participation in the project is voluntary.

2. Data may be collected from the participants in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.

3. Data obtained from the participants during the research project may be used in the writing of the PhD thesis, reports or published papers and making presentations about the project. This data will be reported without use of my name.

I can direct any questions to Tiju Mathew Thomas at tm137@waikato.ac.nz or phone number 021492570.

For any unresolved issues I can contact the Supervisors:

Assoc Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Phone: 0 7 838 4769

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Phone: 078384466

I give consent to be involved in the project under the conditions set out above.

Name:__________________________

Signed:_________________________

Date:___________________________

Information letter for the teacher to participate in the Research Study

Date: Feb 2013

Dear Teacher,

I am writing to invite you to participate in a research study for my PhD at the University of Waikato, New Zealand. This study is about observing how students integrate science, mathematics and technology in a technological design context in a technology classroom. This research will look into how students construct knowledge and make appropriate links among science, mathematics and technology when solving a real life problem. This research hopes to achieve a theoretical model that could be implemented in future technology classrooms, to create interdisciplinary and innovative thinkers who can bring in knowledge from various disciplines to solve design challenges of the twenty-first century.

I would like to involve you in this study through the activities below:

1. Audio Recorded Individual Interview (15-20 minutes)
2. Video Recorded Group Discussions with students (10 minutes)

In the interviews my focus will be to identify any previous knowledge from science, mathematics and technology used by the students to construct their design. I may take photographs of the final designed product and make some research analysis through their portfolios. Group Discussions with students will focus on your perceptions and thoughts about the whole process of linking science, mathematics and technology in the classroom.

Data collected during the study may be used in writing reports, publications or in presentations. We will not use your name, the name of your school or the names of other participants in any publications or presentations. We will make sure that we store all the information we gather securely. You can decline to be involved in the research by not taking part in the interviews. If there is a withdrawal, we will destroy any data gathered from that participant.

We would appreciate your consent to be involved as described. If you need any more details about the project, or issues arise for you during the project, please contact me at tm137@waikato.ac.nz or phone number 021492570. If I am unable to resolve your concerns, you may contact my research supervisors as follows:

Assoc Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Phone: 0 7 838 4769

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Phone: 078384466

Yours sincerely

Tiju Mathew Thomas

PhD Student

University of Waikato

Ph: 021492570

Research Consent Form (Teacher)

I have read the attached letter of information.

I understand that:

1. My participation in the project is voluntary.

2. I have the right to withdraw up until two weeks after receiving any summary of interview from the researcher.

3. Data may be collected from me in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.

4. Data obtained from me during the research project may be used in the writing of the PhD thesis, reports or published papers and making presentations about the project. This data will be reported without use of my name.

I can direct any questions to Tiju Mathew Thomas at tm137@waikato.ac.nz or phone number 021492570.

For any unresolved issues I can contact the Supervisors:

Assoc Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Phone: 0 7 838 4769

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Phone: 078384466

I give consent to be involved in the project under the conditions set out above.

Name:__________________________

Designation: __________________________

Signed:_________________________

Date:___________________________

Please return this form to the researcher by hand (where appropriate).

Information Letter for the Parents and Students to participate in the Research Study

Date: Feb 2013

Dear Student (and your parent/caregiver),

I am writing to invite you to participate in a research study for my PhD at the University of Waikato. This study is about observing how students use knowledge and skills in a technology classroom while designing a product. The research outcome will be a detailed description of how students actually work in a technology classroom to provide a rich learning experience for the students in future.

I would like to involve you in this study through the activities below:

1. Observing by taking field notes on how you work in a technology classroom to design the product. I will not be participating in any of the classroom activities.
2. Answering a questionnaire in each school term which should take approximately 10-15 minutes to complete. You can collect the questionnaire during the technology period and hand in the completed form to me in the next consecutive technology period.
3. Possible involvement in audio recorded group interviews (Three groups of four students for 15-20 minutes) towards the end of Term 2 and 4 with your permission.
4. Analyzing your technology portfolio to collect some data at the end of Term 4 (please note this analysis process will not interfere with your normal school assessment)

Data collected during the study may be used in writing my PhD thesis, reports, publications or in presentations. Students will be required to identify their names in the questionnaires and during the interviews which will help analyze the data towards the end of the study. However, I will not use your name, name of your school or the name of your teacher in any publications, the PhD thesis or presentations. I will make sure that all the information gathered is securely stored. You can decline to be involved in the research by not completing the consent form. If there is a withdrawal after previous consent has been given, I will destroy all the data gathered from the participant. If you decline your participation in between and decide to withdraw, you will still remain in the class and your academic work would be unaffected. Your work may still be observed as part of the group, but it will be not be used for my analysis, and you would not be required to fill in any questionnaires nor participate in focus group interviews.

If you are willing to participate, please show this letter to a parent and caregiver, and if they are willing to allow you to participate, please both sign the attached form and return to the researcher in your technology classroom. If you need any more details about the project, or issues arise for you during the project, please contact me at tm137@waikato.ac.nz or phone number 021492570. If I am unable to resolve your concerns, you may contact my research supervisors as follows:

Assoc Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Yours sincerely

Tiju Mathew Thomas

PhD Student

University of Waikato

Ph: 021492570

Research Consent Form

(Student participation in filling Questionnaires/Interview/Discussions)

I have read the attached letter of information.

I understand that:

1. My participation in the project is voluntary.

2. I have the right to withdraw up until two weeks after receiving any summary of interview from the researcher.

3. Data may be collected from me in the ways specified in the accompanying letter. This data will be kept confidential and securely stored.

4. Data obtained from me during the research project may be used in the writing of the PhD thesis, reports or published papers and making presentations about the project. This data will be reported without use of my name.

I can direct any questions to Tiju Mathew Thomas at tm137@waikato.ac.nz or phone number 021492570.

For any unresolved issues I can contact the Supervisors:

Assoc Prof John Williams (Chief Supervisor)

Email: pj.williams@waikato.ac.nz

Phone: 0 7 838 4769

Dr Michael Forret (Co- Supervisor)

Email: m.forret@waikato.ac.nz

Phone: 078384466

I give consent to be involved in the project under the conditions set out above.

Student Name: Parent Name:

Signed: Signed:

Date:

Please return this form to the researcher by hand (where appropriate).

APPENDIX B

Questionnaires, Data and Interview Questions
Stage 1

Term 1 (Stage 1) Student Questionnaire

The purpose of this questionnaire is to get your ideas about technology. Please answer all of the questions. Your responses will remain anonymous; I just need your name to match with other data.

The responses provided in this questionnaire will be used for the purpose of gathering research data only.

Name:

1. Why did you choose to take technology this year?

2. Do you find your technology sessions interesting? Why?

3. What do you want to do when you leave school?

4. How many technology classes have you taken before this one?

5. How and from where did you collect information to decide:
    a. How a luge works?

    b. Components for your luge?

    c. Materials for your luge?

    d. Types of Luge?

6. Do you have any previous experience of designing and making?

7. Will you be doing any background research by yourself as you do your design?

8. Do you think this project is relevant to you? Why?

9. Do you have any prior experience driving a luge?

10. Do you anticipate you may need knowledge from other subjects to complete your design?

11. What skills do you think you may need in your design?

Practical/Hands-on Skills:
Minds-on Skills:

Thank you for filling out the questionnaire. Your response is very important for this research.

Teacher Interview Questions - Term 1

1. What initiatives or approaches have you introduced in term 1 to integrate science, mathematics and technology?

2. What were the outcomes of such integration?

3. How will you try them out in a different way next time?

4. What is the rationale behind product reading and discussions around them? Is it a good stage to integrate cross-disciplinary knowledge?

5. Should students be allowed to play with materials before they actually start designing in terms of integration?

6. Apart from your teaching, do you think students are somehow absorbing the knowledge and skills necessary to design?

7. Do you think students need prior knowledge before they start designing? Which areas of knowledge do you think is important for them?

8. Do you think students also integrate science, mathematics and technology naturally while doing technology?

9. Will it be productive to integrate cross-disciplinary knowledge during the actual making process in next term?

10. Why is it important to give real life examples in a technology classroom? Are they a means to connect what they learn in a classroom to the real world problems?

11. I would like to know about your personal experience while trying to integrate the knowledge of 'tensile and compressive' forces to the students during the testing of materials? Do you think it was significant piece of information for the students?

12. Students in your classroom mentioned they enjoyed the practical aspects of things in technology. Do you think 'testing' in a technology classroom has a potential to integrate cross-disciplinary knowledge?

13. A chat about what the goals are related to integration, beyond just doing a good design. Is it an important life skill? How? Are there ways to help ensure that the skill becomes transferable, beyond just what is done in class?

Term 1: End of Term Questionnaire

I would like your views and opinions about working in a technology classroom. Please answer all of the questions, your responses will remain anonymous and will only be used for gathering research data.

Name:

1. Please list the subjects (Science, English, Economics, Arts etc) you took in Year 10?

2. What Knowledge from the subjects listed above (Year 10) will be helpful to complete your design of the luge?

3. Please list the subjects are you taking in Year 11.

4. What Knowledge from the subjects listed above (Year 11) will be helpful to complete your design of the luge?

5. Is it important with respect to your luge to have knowledge from other subjects to complete the design?

6. What specific knowledge from the subjects (Year 10 and 11) have you already used in term 1 to design the luge? Please be specific. An example has been done for you.

Subject(s)	Topic(s)
Arts	Drawings, artist models, pictorial composition

Biology	Nerves and Hormones, Evolution, Adaptation

7. What more information do you need before you begin the construction of your luge?

Luge Research Phase

8. Did the 'luge research' phase help you identify factors which will affect the performance and speed of your luge? Please explain and list some of these factors.

9. What are your perceptions about product reading (looking at existing products) in technology classroom? Do you think this practice is useful in expanding your knowledge about luges? Explain in 4-5 sentences.

10. To what extent will your stakeholder have an influence over your design? Please tick the appropriate choice

- Not at all
- To a limited extent
- To a fairly large extent
- Extensively

11. Please list all the areas of knowledge you needed (eg. shapes, symmetry, drawing lines) in order to develop your cardboard pattern.

12. Did your practical ‘hands-on’ experiences with hard materials (plywood, resins, fibre glass, hydraulic press, mild steel etc.) contribute to your learning? Answer in 4-5 sentences.
13. How did the information hand-out on the ‘compressive’ and ‘tensile’ forces help you with your understanding of improving the strength of materials?

14. When should have been the knowledge on ‘compression and tension’ provided to you? Please tick the appropriate choice(s). You can choose more than one option.

- Before testing the materials
- During the testing
- After the testing of materials

Please explain the reason for your choice(s):

15. Do you really need to know about ‘compressive’ or ‘tensile’ forces to build your luge?

- Yes
- No
- Not Sure

16. What specific knowledge from other subjects did you use in your:-

a. Momentum Testing

b. Material testing

c. Concept Drawing

d. Cardboard Pattern

Thank you for filling out the questionnaire. Your response is very important for this research.

Student Questionnaire from Stage 2

I would like your views and opinions about working in a technology classroom. Please answer all of the questions, your responses will remain anonymous and will only be used for gathering research data.

Name:

1. To what extent do you understand the reason behind the shape of your body pans?

- o Not at all
- o To a limited extent
- o To a fairly large extent
- o Extensively

2. Do you really need to know the reason behind the shape of your body pan?

- o Yes
- o No
- o Not Sure

3. What skills did you develop while making your body pan and frames?

4. Can you recall why the shape of your body pan is curved?

5. What is the reason behind lowering the body pans more towards the ground?

6. What can you tell about your problem solving abilities in the workshop while making your body pans and frames?

7. Do you think knowledge from other subjects will help you at this stage of making?

    - Yes

    What subject(s) and topic(s)?

Subject(s)	Topic(s)

- No

  Why not?

- Not Sure

Thank you for filling out the questionnaire. Your response is very important for this research.

Student Focus Group and Teacher Interview Questions from Stage 3

Student Focus Group Interview

General Questions

1. Do you think in this whole project there was knowledge recalled from previous years from science, mathematics and technology?

2. Did you require any new knowledge to problem solve in technology classroom?

Momentum Testing

1. If you recall your physics teacher gave you some knowledge about momentum and forces before momentum testing? Was this phase useful? If yes then how? If no then why?

2. What specific science and mathematics did you use while momentum testing?

Luge Research

1. Functioning of Components?

2. Concept Design (any science or maths identified?)

Material Identification

1. While identifying the best materials for the luge, how important is it to know about the physical and chemical properties of materials?

Integration of Knowledge from physics

"The strength of the material before it deforms bends or breaks or whatever. So if we can select your materials and get really good tensile strength in other words they are not breaking then we should test them for those things and we can get the right materials for the right job"

1. How did you utilize this knowledge to design and make your luge or its specific components like body pan or frames? Do you need this information in a technology classroom? Should this knowledge be taught to you while you see it being done practically?

2. Did you have any stakeholder who gave you enormous input in the design and make of your luge? If so what is his/her profession? Did you use any science and maths while involving your stakeholders?

Cardboard Pattern

1. Please detail all science and mathematics used while making a cardboard pattern.

2. Was there any instance where you changed your cardboard pattern (design) and there was a scientific reason behind it?

Body Pan Construction

1. Recall your experience of making the body pan? Any principle of science applied? Any maths applied?

2. You were given the information on why thin sheets of plywood should be used to bent rather than thicker pieces. Do you know the scientific reason behind this? Should the teacher have touched this aspect in more detail in the classroom?

3. Did you take into consideration about the different types of forces which will be acting on your body pan during this phase? If yes please name the forces you thought of?

4. How was your experience of drawing circular curves onto your body pans? Was it easy? How sis you do it?

5. Your internal standards required you to learn about the arrangement of grains and cells in the plywood and the direction in which the maximum strength was obtained. Biological aspects like cellular structure, cells and its growth was touched upon in the context of a tree and how its arrangement gives the required tensile strength. How did you use this information for your luge?

Frames (steel and wooden)

1. Discuss in detail any science and maths used in this particular phase of the project?

2. Did you take into account all the forces which will be acting on your body pans and frames combined at this stage? Explain

3. While making the frames was it important to consider any science or maths? If yes how did you apply them to your project?

4. How did you make your frame structurally strong and stable taking into the account you will be laying down on them?

5. Is there any scientific reason behind lowering the body pan more towards the ground?

Truck Plates (picture)

1. Identify any maths used while making your truck plates?

2. What were the different types of bolts you used for constructing your luge? Do you need to know why different bolts are used for specific purposes or hole sizes?

Weight distribution (picture)

1. What science/maths can you identify at this stage?

2. Did you get the whole idea of weight distribution while it was discussed in the classroom and why it has to be 60:40?

3. After testing your luge are you fully satisfied with your weight distribution?

Where and when did you use the following instruments in your project?

1. Set squares,
2. T squares,
3. Protractors,
4. Compass,
5. Callipers

4. Are you happy with the whole structural integrity of your project?

5. Do you think after making your luge you have a better understanding about the working and functioning of its components?

6. How was your experience of applying mathematics to your project? Can you provide an example?

7. How was your experience of applying science to your project? Can you provide an example?

8. Was there any instance where you made a changed in your project and there was a scientific reason behind it?

9. After driving your luge finally are you happy with the amount of bent your body pans?

Integration Questions

1. In future technology classrooms do you think there should be collaboration with other departments like science and mathematics to make connection to what you are doing in a technology workshop?

2. Do you think your science teacher should get involved in a technology classroom? What sort of help would you seek from them in case they did?

3. Do you think your maths teacher should get involved in a technology classroom? What sort of help would you seek from them in case they did?

Teacher Interview

1. What science and maths principles or concepts were utilised by the students while making their luges?

   Body pans
   Frames
   Body pan + Frames (bracing and metal straps)
   Weight distribution
   Bolting and screwing
   Footrest and headrest

2. How the concept of momentum taught to the students? Was the concept easy for them to understand? How did they apply it to their project?

3. Comments on students adding braces and metal straps on to their frames to support their body weights and to make it structurally stable. Was there high level of understanding and thinking shown by students while doing this?

4. Did you encounter any trouble explaining any engineering, science or mathematics concept to the students?

5. Do you think students work in a technology classroom without realising the science, engineering and mathematics concepts they use while making their projects? Is it important for the students to know if it is science or maths?

6. What did you except in terms of integration this year? Was there considerable self-initiated integration?

7. What should be the right balance between the theory (concepts, principles) and practice in a technology classroom?

8. What would you try new in terms of integration (STM) next year?

9. Ideally how would an integrated learning environment would be carried out or be practical to students?

APPENDIX C

Data from Student Questionnaires

Table C.1 Students' experience in technology classroom

Student	Yes	No	Response
ST	Y		I have worked on scooters, weather stations, phone holders and carbon dioxide cars
BA	Y		
KM	Y		
JV	Y		Done in last 4 years
MQ	Y		Every other year in this school
HM	Y		3 years in a row. Last year making carbon dioxide car and scooters
JP	Y		Little bit in my old technology classes
TJ	Y		3 years of technology in school. Made carbon dioxide dragsters
LG	Y		Taken technology since year 7. I have constructed a 2m long and 3m wide half pipe, scooter and several small projects
TN	Y		2 years
MC	Y		2 years
JC	Y		Y9 and Y10
DC	Y		From previous technology classes (3 years)
DR	Y		Technology from last year with arts
JS	Y		Since Y7
SS	Y		1 year
EM	Y		3 years of technology. Last year I designed and made scooters.
MY	Y		3 years. From my previous technology classes and my granddad who is a builder.
TG	Y		2 years

Response on how did the information hand-out on the 'compressive' and 'tensile' forces helped students with the understanding of the strength of materials

Table C.2. How the information hand-out on the 'compressive' and 'tensile' forces helped students with the understanding of the strength of materials

Student	Perception
LG	It helped me decide how to make my luge strong but light
EM	It helped me by showing that there is more to think about than just a broken material. When something is breaking you can see why it is breaking
MY	It helped by explaining what each material is capable of doing and what to use it for and how to make it stronger
TW	Because it helped me to understand what materials should I be using
JP	It showed me the maximum strength of the materials and the sizes it came in so I could widen my range of materials
TG	It helped a lot as I now know what happens when something compresses
MC	It showed us what materials are the strongest and the most bendable to use on our luge
JV	It gave me a greater knowledge on how tensile strength is created with materials
DC	We could test the materials in various ways and examine the results
TJ	It helped with bending materials and strength of materials
KM	It helped me to pick up the materials to use for my luge
JS	It made me understand it all better
HM	Yes because I did not really get it until I got the hand-out
MQ	Learned about tension and compression in materials and how that affects its strength
BA	It helped me by telling me in another perspective
SS	It helped me that materials with fibreglass are stronger at the bottom because it is harder to stretch
DR	It helped me that the material I used, i.e. fibre glass makes our material stronger if it is at the bottom because it is harder to stretch and holds it together
JC	It showed me the best places to add strengthening materials
ST	I learned about tension and compression in materials and how it affects it

Responses provided by the students as to when the knowledge on ‘compression and tension’ should have been provided in the classroom.

Please tick the appropriate choice(s). You can choose more than one option.

- o Before testing the materials
- o During the testing
- o After the testing of materials

Table C.3 Student responses on timing of materials testing

Student	Is it Important?	Choice	Perception
LG	Yes	During testing	Because we can apply it during the testing
EM	Yes	During testing	While something is breaking you can see why it is breaking
MY	Yes	Before testing	Because then I know and am aware of the different sizes and what compression and tension does
TW	Yes	During testing	So we know more about material testing
JP	Yes	During testing	So we could test the materials then actually do a bit of study on the material and then get back in the workshop and physically test again
TG	Yes	After testing	Because we wanted to know what happened so we took it on board more
MC	Yes	Before testing	Because we get to see the compression and tension while it happens and we can understand it better
JV	Yes	During testing	Because it would help us understand what happening when we are testing
DC	Yes	Before testing	So we could test the materials in various ways and examine the results
TJ	Yes	Before testing	Because then we would have known more about tensile strengths
KM	Yes	Before testing	Because you will be able to understand what is happening while testing
JS	Yes	Before testing	So we could know what we are going to do and how it works
HM	Yes	Before testing	Because we know what to put on it if it need strength for plywood
MQ	Yes	During testing	So that before I make my luge I know how and what materials to use
BA	Yes	During testing	I believe this was important because I could

			understand things better
SS	Yes	During testing	
DR	Yes	During testing	Because if you see a practical while learning about material, I find it easier because I am visualising it
JC	Yes	During testing	If we saw at first that the materials snapped, then saw how the forces worked, it would give us a better understanding of it
ST	Yes	After testing	So I know how material work when compressed. This will therefore determine what material are best to use for my luge

Question: Did your practical 'hands-on' experiences with hard materials (plywood, resins, fibre glass, hydraulic press, mild steel etc.) contribute to your learning?

Table C.4. How practical 'hands-on' experiences with hard materials contributed to student learning

Student	Response
LG	I already understood most of what was shown, but it helped refine my ideas
EM	This helped me by showing me about tensile strength of a material and how flexible a material is. The resin showed me that a liquid can be really strong
MY	Yes because now I know for example to put fibre glass in my plywood otherwise it will snap because it's not strong enough
TW	Yes because it helped me decide which materials are going to perform better for my luge and what will weigh less
JP	Yes because I could physically see how strong and the limits my material were that I was using for my luge
TG	Yes it did as I knew what to do and I could help others because in the past I had done it before
MC	Yes, the practical things showed us what materials is good to use on a luge. It also showed us what material is the strongest to use on the luge. It also showed us what materials look the best.
JV	Yes it helped me get to know the strength of the materials and gave me ideas of how the materials could be manipulated to make them stronger
DC	Yes, because it allowed us to get a feel for the process. It allowed us to learn the best ways of carrying out the process
TJ	Yes because it taught me how to bend and cut and work with products
KM	Yes because it helped me to understand what materials were stronger (tensile strength)
JS	Yes cause we get a test of what we are going to use
HM	Yes because it is getting an idea of what the material is about
MQ	Yes, because I learnt about strengths or materials. This was tensile and compressive forces in materials. Also learnt about laminating plywood.
BA	Yes, because we test for the right and most sufficient material we need. This will help our luge to be successful one
SS	Yes it is showed me which materials would be the most cost effective but also has the strength factor
DR	Yes it showed me which material would be the most cost effective, but also has the strength factor
JC	Working with plywood helped me to understand it better. The work on the hydraulic press helped me to learn how it works. Working with the resin showed me that it dry's fast and you need to be quick

ST	It gave me a good idea on what materials can withstand a greater amount of weight. Additionally how the material deformed whilst being compressed

Question: What specific knowledge from other subjects have you already used in Term 1 to design the luge? Please be specific.

Table C.5 Specific knowledge from other subjects already used in Term 1

Student	Subject(s)	Topic(s)
LG	Maths	Basic addition
	Science	Gravity
EM	Maths	Measurements
	Science	Momentum
MY	Maths	Basic addition
	Science	Aerodynamics, gravity etc.
TW	Maths	Measurements
	Science	Gravity, weight, forces
JP	Maths	Measurements
	Science	Gravity, weight, forces
TG	Maths	Measurements
	Science	Momentum, weight distribution
MC	Maths	Measurements
	Science	Momentum
JV	Maths	Measurements
	Science	Forces and motion
DC	Maths	Speed and time
	Science	Aerodynamics and gravity
TJ	Maths	Measurements
	Science	Environmental resistance
KM	Maths	Measurements
	Science	Momentum
JS	Maths	Measurements
	Science	
HM	Maths	Measurements
	Science	
MQ	Maths	Measurements
	Science	Physical properties
BA	Maths	Angles, trigonometry
	Science	Aerodynamics
SS	Maths	Measurements
	Science	Movement

DR	Maths	Measurements
	Science	Momentum, aerodynamics
JC	Maths	
	Science	
ST	Maths	Measurements
	Science	Physical properties

Question: Is it important with respect to your luge to have knowledge from other subjects to complete the design?

Table C.6 Importance of knowledge from other subjects in Luge design.

Student	Perception
LG	Because it need design ideas and helps to fix any flaws in my design
EM	Because it can help you do things not just welding etc. It can help you write up essays and work out angles
MY	Because without the math knowledge you would not know about sizing. Without physics you don't have any idea on aerodynamics and gravity.
TW	So it looks good and works properly
JP	So we can make a more accurate safe and faster luge
TG	Luge needs measuring, physics of weight distribution and forces like gravity
MC	Because you wouldn't know much about momentum or physics making it extremely hard to make a luge that would work
JV	So that you can produce a better luge, so that it will be faster and more aerodynamic and to get the right sizes
DC	It is important to have knowledge from other subjects so we can design our luge based on different i.e. physics
TJ	So all the measurements can work together to make luge fit together
KM	Because it could help me to further develop my luge and make better change
JS	To be able to measure equipment and materials also assignments and the writing side of it
HM	So we can measure correctly and write about it
MQ	It is important to have knowledge from other subjects to complete our luges so we can add in skills for making the luge
BA	Because it can show me how to do different things I haven't done before
SS	Because it can help me further develop my luge and make better changes
DR	If I can do maths, I can't work out my measurements. Building and construction helps me prepare to cut and make my luge design with materials that work. Science helps me find which kind of shape for my luge will be the most aerodynamic
JC	Because I can carry our things I have learned to improve designs
ST	It is important to have knowledge from other subjects for the completion of our luges as there are many skills we need to incorporate

Responses by students on problems faced by the students while doing technology

Table C.7 Problems faced by students in doing technology.

Student	Response
SS	Could not get the measurements right at the first time probably referring to the lines of symmetry and curves
JP	Measurement and working with the drills (process)
NT	Sanding, gaping, drawing and cutting the curves on to the body pan
JC	The processing of the body pan and coming up with symmetrical curves
KM	hard to cut out the sides after drawing and steep curves and rectangular shapes, measurements, sanding and sowing
TJ	there was no particular issues encountered as he said his was a simple design
BA	measurements was a problem as he had to redo his measurements again because he did not get the lines of symmetry right the first time
MQ	to clean cut and cutting out the corners after the measurements
EM	putting the plywood together, gluing and getting the right amount of bent were an issue initially. Getting the measurements transferred from the cardboard pattern to the body pan was another issue because the plywood was bent. Processing of the body pan cutting and sanding came thereafter
HM	cutting the curves on the body pan was a problem because it was curved (body)
DC	Nothing not really just minor problems like cutting and sanding. Measurements like lining it up and tracing the pattern on to the plywood and machinery but made it simple all together
TG	putting the measurements on to the plywood and cutting it out because certain shapes like curves not simple to cut but not hard. Sides came out but he glued it to make it look better
DR	cutting the sides was an issue but the measurements were fine and pretty good
MY	to cut it out, putting the measurements on to the plywood, getting it nice and smooth around the sides
MC	hard a measure as the pans were bent in shape
JS	trouble gluing up the plywood together as it was obvious the bottom layer was coming off, layers were short at the bottom (was ripping off) so I had to figure something out for that. Measurements were not a problem as my design was a simple one

APPENDIX D

Required resources and approximate cost for the study

Table D.1: Resource Requirements

No.	Activity	Estimated Budget (NZD)
1.	Travelling for Conferences	800
2.	Printing informed consent forms, questionnaires, focus group interview notes	150
3.	Research Instruments (audio recorders)	200
4.	Researcher Incidental Cost	50
5.	Thesis Binding	200
	TOTAL	**1400**

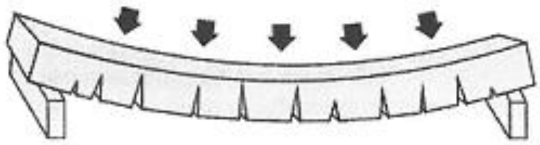
APPENDIX E

Handout on Tension and Compression

Compressive and Tensile Force

A **beam** is a structural element that is capable of withstanding load primarily by resisting bending. The bending force can be induced into the material of the beam as a result of the external forces or its own weight. The force on the top half of the beam is squeezing the beam together. The force on the bottom half of the beam is stretching it.

The squeezing force is called **compressive (pushing) force**.
The stretching force is called **tensile (pulling) force**



The diagram below shows what happens inside a rectangular beam when it carries a load. As you can see the greatest compressive force acts at the top of the structure and the greatest tensile "pulling" force acts at the bottom of the structure.

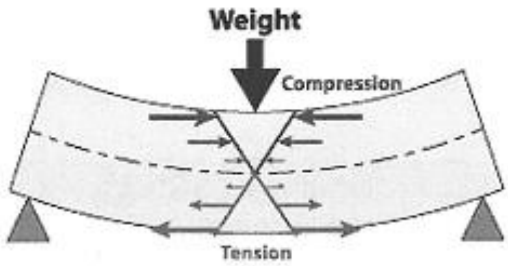
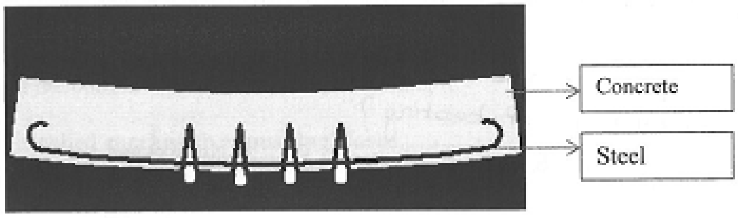


Illustration with a real life example

The force in the top half of a beam is compressive. Many civil engineering structural building elements such as concrete have a good compressive strength and can withstand this force. Concrete has very little tensile strength and will easily tear at the bottom of the beam. On the other hand, steel is very strong and can easily withstand the tensile forces. The steel is placed at the bottom to withstand the tensile force. The steel reinforces the concrete. The beam is called a **reinforced concrete beam** as shown below.



Beams are traditionally descriptions of building or civil engineering structural elements, but smaller structures such as truck or automobile frames, machine frames, and other mechanical or structural systems contain beam structures that are designed and analyzed in a similar fashion.

Think about these questions by yourself

1. Why is there no force on the middle of the beam?
2. What implications does this piece of information have for your luge?

APPENDIX F

The Intercoder Reliability Agreement

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.1143	77.27
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	83.15
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	94.81
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	96.81
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0416	91.86
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	91.78
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	85.19
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	94.81
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	94.87
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Descriptive Knowledge (	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	98.44
Descriptive Knowledge (	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	95.97
Descriptive Knowledge (	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Perceptions (classroom	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	98.21
Perceptions (classroom	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	97.69
Perceptions (classroom	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	97.56
Perceptions (classroom	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	98.21
Perceptions (classroom	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Perceptions (classroom	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Perceptions (classroom	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
Perceptions (classroom	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	97.69
Perceptions (classroom	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	97.56
Perceptions (classroom	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Perceptions (classroom	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Perceptions (classroom	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.1025	77.39
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	98.43
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0712	84.98
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0328	93.57
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0327	91.41
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	95.4
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0386	92.31
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	98.43

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	99.06
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	99.06
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Social Constructivism a	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Social Constructivism a	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	90.54
Structural Rules	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules\Scienc	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Structural Rules\Scienc	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules\Scienc	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules\Tool Int	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	90.54
Structural Rules\Tool Int	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Structural Rules\Tool Int	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Student Derived	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	98.61
Student Derived	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	92.07
Student Derived	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	95.23
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
TACIT Knowledge (Pers	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
TACIT Knowledge (Pers	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.1154	79.05
Teacher Derived	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Applie	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Teacher Derived\Applie	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Applie	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Applie	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Teacher Derived\Applie	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Applie	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Mathe	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Teacher Derived\Mathe	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
Teacher Derived\Mathe	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Non S	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	95.33
Teacher Derived\Non S	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Non S	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Prior K	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Teacher Derived\Prior K	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Prior K	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Proces	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	-0.0866	83.72
Teacher Derived\Proces	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Proces	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Scienc	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Teacher Derived\Scienc	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Teacher Derived\Scienc	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	92.91
Technological Theories	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	98.83
Technological Theories	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	96.93
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	98.83
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	0	92.91
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	97.77
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100

Coding Comparison Query Results

Node	Source	Source Folder	Source Size	Kappa	Agreement (%)
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	0.5	98.86
Technological Theories\	Field Note-15-02-13	Internals\\Richard- Inter R	9755 chars	1	100
Technological Theories\	Luge Evaluation 1	Internals\\Richard- Inter R	1 pages (2 chars)	1	100
Technological Theories\	Luge Evaluation 2	Internals\\Richard- Inter R	1 pages (2 chars)	1	100