As Part of a 21st Century Learning Activity, an Investigation into the Effect of Utilising a Synthesized Problem Solving Model in a Microworld Simulation to Develop Problem Solving Skills in Maths Education

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Declaration

I declare that the work described in this document is, except where otherwise stated, entirely my own work and has not been submitted as an exercise for a degree in any other university.

Signed ________________________ Date: ____________

Ian Boran

Permission

I agree that Trinity College Dublin may lend or copy this project upon request.

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Ian Boran

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Abstract

In 2011, the National Council for Curriculum and Assessment (NCCA) in Ireland introduced the new Junior Cycle Framework in Ireland. This framework was established and designed to prepare our students with a collection of eight key skills of which problem solving skills are highlighted as a key component. Problem solving skills are also imperative in the new mathematics curriculum “Project Maths” which was introduced to post primary schools in Ireland in 2008.

Problem solving has always being an integral part to mathematical curriculums around the world and a vast array of research has been conducted to enhance the teaching and learning of problem solving. Students and teachers have found it difficult to grasp the idea of developing problem solving skills for various reasons. Reviewing the literature has highlighted that the delivery of maths education has often focused on procedures and routine step-by-step approaches to achieve solutions. As a result, levels of disengagement and dissatisfaction have been associated with the teaching and learning of maths.

To address the issue of enhancing student’s skills in problem solving, this dissertation examines existing models and frameworks that assist in problem solving and devises a new model one based on a synthesis of those models. It then investigates the effectiveness of the model in assisting students to develop metacognitive skills (planning, monitoring and reflection) when problem solving. Becoming an efficient problem solver depends on a range of factors including knowledge, skills, attitudes and context. This study will examine the effect on using a synthesised problem solving model to develop one aspect when problem solving, the use of metacognitive skills.

The literature review highlighted the value of incorporating a social constructivist and constructionist pedagogy in educational settings. Research has indicated to the potential benefits this can have in developing levels of understanding, performance and engagement in learning activities among students. Allowing students to be an active part in constructing knowledge can help students when problem solving. Similarly, the affordances of technology in education to transform and refine the learning experience has been documented recently. The affordance of technology to allow students to interact, visualise, design, create and reflect their work in an immersive dynamic learning environment has been highlighted. The use of technology could potentially allow students to develop these skills.

Recent research has shown the Bridge 21 pedagogical model for 21st century learning as being successful in delivering 21st century learning experiences, which incorporate the use of technology. The dissertation uses the Bridge 21 model, to deliver the learning activities

In light of these findings from the literature five key components including 1) the pedagogical approach, 2) the problem solving model, 3) the role of metacognition, 4) the inclusion of technology and 5) a 21st century learning framework, informed the design of the learning intervention created to investigate the research question.

The main research question asked in this study is "*Does the use of the synthesized problem solving model (SPSM), enhance problem solving skills and metacognitive skills when problem solving?"*

An exploratory and explanatory case model was conducted to collect data to address the research questions proposed. A learning intervention was implemented for 8-10 hours over three-week period with a total 21 student participating in the research. The students interacted in a series of problem solving activities using a Microworld simulation while using the synthesised problem-solving model to develop their metacognitive skills.

A convergent mixed methods methodology was used in this dissertation. A mix of qualitative and quantitative data was collected and triangulated to highlight any significant findings in the investigation. The findings from the research highlight a statistically significant increase in the participant's metacognitive skills. The positive role of the Microworld and Bridge 21 learning framework on developing student's metacognitive and problem solving skills is discussed. The limitations of this research are outlined due to the small sample size of participants, however further areas of research are discussed.

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Chapter 1: Introduction

1.1 Background and Context

Internationally and nationally the importance of creating an educational experience for students that will prepare them to succeed in a 21st century and receive a more meaningful educational experience is evident (Fullan & Langworthy, 2013). In Ireland in 2011, the National for Council for Curriculum and Assessment established the New "Junior Cycle Curriculum in Ireland" for Junior Certificate Students. Included in the rationale of the new curriculum, is the need to establish a framework for learning that enables the students to acquire skills that will prepare them for the 21st century. Specifically "problem solving and critical thinking skills" have been highlighted as key skills in this new framework (NCCA, 2011).

In 2008, the new Project Maths curriculum was established in Ireland for Junior and Leaving Certificate Students as a pilot programme and in 2010, the programme was launched nationally. Project Maths was introduced enhance the approach to the teaching and learning of mathematics. The design of the syllabus allows students to discover maths through inquiry and discovery through a problem-orientated contextual learning experience for the students (Jeffes et al., 2013).

Given the introduction of the new curriculums and frameworks in Ireland, the importance and emphasis on developing students critical thinking and problem solving skills is evident. However, incorporating, developing and preparing students with these new skills can be challenging. Traditional and direct teaching methodologies have been criticised for failing to develop, engage and enhance critical thinking and problem solving skills (Fullan & Langworthy, 2013)(Bray & Tangney, 2015).

Research has indicated that maths can be perceived to be a set of rules and procedures, ignoring the underlying relationships, properties that underpin mathematics (Hoyles, 2016). Frequently in schools, standard approaches are more than often utilised to achieve the correct answers. Very often, the process of reflection or recognition is not carried out to generalise the skills they used to tackle the problem. Repeatedly students cannot recognise the skills that they are using while solving problems and significantly that they can and should apply these skills when undertaking new problems (Geraniou, Mavrikis, Hoyles, & Noss, 2008).

The process of problem solving can be challenging. The techniques used to represent a problem and how to develop or represent a model of the problem can be difficult and are not always obvious. There are many different levels to problem solving tasks that may require one to use multiple skills including; memory, expertise and knowledge or creative approaches to gain new knowledge.

Additionally, it requires the brain to develop, identify, and comprehend various perspectives and ultimately decide on a potential path to solve the problem. The use of these higher orders thinking skills can be challenging and can be difficult on the working memory load of students, which can challenge their cognitive ability. Sweller (1988) outlines that the cognitive loads that a student can experience when attempting a problem for the first time without a support structure or learning framework are demanding.

Furthermore, the research outlined by (Stevenson, 1925) on the difficulties that students encounter when solving problems still apply to students in the 21st century. These difficulties include; lack of skills, students mentality, literacy and numeracy problems, and the absence of methods or techniques for addressing problems.

1.2 Pedagogical Approaches

Current discussions on how to develop and enhance levels of student engagement in education are arguing for educators to adapt and transform their teaching methodologies used, in order to be able to prepare students with a 21st century learning experience. Many educators and researchers argue that applying a didactic, transmissive teaching methodology may no longer be adequate (Fullan & Langworthy, 2013) (Li & Ma, 2010). The design of student centred learning environments, that allow for constructivist pedagogies that enable students to apply critical thinking skills, have been proven to increase motivation and deeper levels of understanding (Handelsman, Briggs, Sullivan, & Towler, 2005).

From the cognitive learning realm, two theories will be applied, Constructivism and Constructionism. Constructivism is a learning theory with the principle focus on the creation of knowledge. Information is constructed via the learning interactions that are produced in social activities (Ackermann, 2001) (Piaget , 1955). The Social Constructivism theory outlined by (Vygotsky, 1978) outlines the advantages of collaborative learning as a process of developing conceptual learning. The effects of setting, context and interactions can have an impact on how one learns.

Constructionism is a learning theory established by (Papert, 1980). The underlying concept in this learning theory acknowledges that learning is at its best when learning is accompanied by the creation of artefacts while working with others. Using a constructionist approach allows students to create their personal knowledge as opposed to receiving prepared information (Voogt & Pelgrum, 2005).

An interesting example where the creation and construction of knowledge are intrinsic components to the design of the curriculum is Realistic Maths Education (RME). This learning model was developed by the Freudenthal Institute in the Netherlands with a core feature promoting contextualised mathematics in the teaching and learning of mathematics. The aim of this model is to promote higher order thinking and collaborative skills when understanding maths. Problem solving is a key component in their curriculum, challenging students to creatively construct solutions to realistic problems. The model enables students to develop their conceptual understanding of topics which can allow for deeper and more meaningful learning experiences.

1.3 Problem solving Approaches

Reviewing the literature on problem solving, a number of frameworks and strategies used when problem solving have been developed. The heuristic practices established by Polya (1945, 1954 and 1981) outline four main stages that one must complete when addressing a problem. These include; understanding the problem, devising a plan, carrying out the plan and looking back (Polya, 1981) (Leong, Toh, Tay, Quek, & Dindyal, 2012). Within Polya's method the importance of metacognition and reflection are emphasised in order to develop conceptual levels of understanding (Schoenfeld, 2007). Other problem solving methods include Resnick & Glaser (1976) and Isaken and Trefinger's (1985) strategies which have similar characteristics to Polya's heuristics but differ in the steps required and language used in their methods.

Wing (2006) described Computational Thinking (CT) as a way of "solving problems, designing systems and understanding human behaviour by drawing on the concepts of computer science" (Wing, 2006, p. 584) and the incorporation of (CT) into mainstream education has increased in recent years. CT has similar set of heuristics to the problem solving approaches outlined by Poyla et al. The aim of the CT model for thinking is such that it can be applied in multiple contexts and environments to allow students to practice their skills in problem representation, problem decomposition, simulation and abstraction (Kalelioglu, Gulbahar, & Kukul, 2016).

In 2016, Kalelioglu, Gilbahar and Kukul established a framework for computational thinking as a problem-solving process. These guidelines include five main steps that are preformed when attempting problem solving. These include, “identify the problem, gathering and representation of data, generating a plan, implement your solution and review and assess your solution for improvements” (Kalelioglu et al., 2016, p. 593). Comparing this model to Poyla’s strategy there are numerous similarities in the steps required when problem solving. This framework identifies the importance of metacognitive skills when problem solving.

1.4 Role of Technology

The incorporation of technology in education has increased in recent years. The effect on the use of technology to enhance the teaching and learning environment has been widely documented. Olive et al (2010), outlines the influences that technology can have on encouraging new forms of learning and redefining learning environments. Modern technologies can allow for collaboration between learners, representation of complex and abstract scenarios through the use of simulations and modelling (Geiger, Faragher, & Goos, 2010),(Olive et al., 2009). Research has highlighted the affordances of technology to facilitate experimentation and testing of ideas, as well as for modelling and the visualisation of abstract mathematical concepts, can contribute to student’s understanding of mathematics (Fang & Guo, 2016),(Bray & Tangney, 2015). In addition, the incorporation of suitable technology in a constructionist learning environment, can enable students to be central to the learning process by investigating hypothesises and visualising their ideas with technology (Olive et al., 2009).

Research conducted in engineering education has revealed the impact that simulations can have on students being able to the interact with the spatial movement of a mechanical system. Evidence has indicated that students tend to develop a greater understanding of the relationships and underlying principles (Fang & Guo, 2016)(Kozhevnikov, Motes, & Hegarty, 2007). Similar to simulations the affordances of Microworlds have highlighted the potential of technology in learning activities. Reiber (2005) has defined Microworlds as computer systems that allow the learner to perform three main functions. Firstly, the learner can interact with and explore underlying concepts. Secondly, the software can enable users to build concrete knowledge based on understanding of the concepts and finally in a Microworld the learner constructs knowledge by being active in the learning process.

Incorporating technology in problem based learning environments can enable the students to creatively and critically carry out the steps involved in the problem solving process. The affordances of technology can allow students to represent and create the internal representations that students have when attempting to complete a problem (Hannafin & Land, 1997) (Li & Ma, 2010). Empowering the students to critically review their ideas and solutions with the use of technology allows the students to become responsible for the learning, resulting in a metacognitive level of understanding on how they addressed the problem (Savery & Duffy, 1995).

1.5 21st Century Learning Frameworks

Incorporating constructionist and constructivist pedagogies with technology in traditional didactic and transmissive learning environments has be proven to be difficult (Tangney, Bray, & Oldham, 2015). Donnelly et al (2011) state that until sufficient evidence is produced to highlight the benefits and skills that can be attained via a 21st century learning environments, educators will be slow to adapt from traditional teaching methodologies.

Fullan (2014) argues that in order to create meaningful, deep learning experiences a change in the role of the learning environment and teacher is needed. New pedagogies are needed to allow for rich learning environments that will enhance students learning so that they are actively creating, participating, and evaluating the success of their learning (Fullan & Langworthy, 2013).

The dynamic relationship in incorporating technology with appropriate technologies is important. Bray's (2016) research on the incorporation of technology in traditional educational settings has highlighted that technology was most beneficial when used with cognitive learning strategies. Bray, argues that the utilisation of technology to achieve its perceived potential is most beneficial when introduced with the appropriate learning environment. Using the constructionist learning theory with suitable technology can have the potential to facilitate contextualised, problem solving approaches to learning mathematics.

Scaffolding, in this context, is a process through which more knowledgeable others (teachers, peers, or tools) provide cognitive and social supports designed to augment student problem solving (Kim & Hannafin, 2011). To be successful in delivering a curriculum that prepares the students to be creative, connected, collaborative and lifelong problem solvers, will require a change in approaches used to deliver education

(Tangney et al.2015). The Bridge 21 learning model is one of many 21st century learning models. Bridge 21 has been proven to promote student engagement, activity and motivation in learning environments with the successful incorporation of technology (Conneely, Girvan, & Tangney, 2012). The model allows teachers to become a facilitator of the learning experience and scaffold the learning experience that encourages students to become active and responsible for their learning.

To address the issue of enhancing student's skills in problem solving, this dissertation examines existing models to assist in problem solving and devises a new model based on a synthesis of those models. The effectiveness of the model in assisting students to develop metacognitive skills (planning, monitoring and reflection) when problem solving is investigated. Developing problem solving skills is a complex process. The approach and environment used when developing these skills is important. This dissertation examines the role of the Bridge 21 learning framework and the use of a Microworld to deliver a problem solving learning activity designed to develop students metacognitive skills when problem solving.

1.6 Research Goal and Methodology

To address the challenges proposed in this chapter, this dissertation will investigate the following research questions:

> *Q1. Does the use of the synthesized problem solving model (SPSM), enhance problem solving skills and metacognitive skills when problem solving.*

The following are sub questions that will be investigated in this research.

> *Q2. Sub Question: What role / impact did the Microworld simulation in the process?*
>
> *Q3. Sub Question: What role did the Bridge 21 learning environment have on the process?*

This investigation will use an exploratory case model to address the research questions proposed. A sample of 21 students were selected to participate in learning activity lasting between 8-10 hours in duration over a three-week period. A convergent parallel mixed methods approach was conducted to collect data. A series of qualitative and quantitative data was generated through the use of questionnaires, focus group interviews, student artefacts and observations of the learning experience. A triangulation of the findings was conducted and findings and conclusions are presented. Limitations to the research are highlighted including the small sample size and length of learning intervention are recognised. Further and potential areas of research are presented.

Chapter 2: Literature Review

2.1 Introduction

This chapter will discuss a review of the literature that has informed the design and foundations of this case study. The literature review will highlight important topics that have influenced the design and construction of the learning experience to address questions proposed in this study. In particular, an examination of the challenges that students encounter when attempting problem solving, difficulties that educators experience when incorporating problem solving in the classroom and current approaches to problem solving techniques are discussed. Firstly (1), the review will analyse the background and context of problem solving in education. Secondly (2), models used to enhance problem solving skills are discussed. Following this, the chapter will present (3) the cognitive pedagogical approaches of constructivism and constructionism and discuss their impact on creating enhanced learning environments. The importance of developing and utilising (4) metacognitive skills are considered and their impact on developing problem solving skills. The (5) affordances of technology in education are presented, specifically the use of Microworlds to promote inquiry and critical thinking skills in problem solving. Finally, the chapter reviews the incorporation of a (6) 21st century learning framework Bridge 21 to deliver the problem solving activity and discusses the aim of 21st century learning frameworks.

2.2 Background and Context

A clear emphasis on the importance of problem solving in education can be seen in various educational curriculums in the past and presently (Ncca, 2011) (Schoenfeld, 2007) (F. Lester, 2016). Mathematical governing bodies have outlined the significance on learning to solve problems, with many stating this as a core principal (F. K. Lester, Garofalo, & Kroll, 1989). Both internationally and nationally the value of developing problem solving skills is appreciated.

However, Fullan & Longworthy (2013) argue that student engagement in education is a real concern for educators. Taking this into consideration, the interest of improving problem solving skills with technologies must be considered. Evidence to highlight that a introduction of technology to teaching and learning can potentially enhance the educational experience for students has been widely accepted (Voogt & Roblin, 2012). Nonetheless research has revealed that unless the use of technology is incorporated with appropriate pedagogies, these improvements may be not seen (Kim & Hannafin, 2011) (Tangney & Bray, 2013) (Fullan & Langworthy, 2014). Similarly, Kim & Hannifin

(2012) maintain that evidence of effective problem solving teaching and learning with the incorporation of technology in learning environments is limited. This highlights the complex nature of problem solving and emphasises the argument that problem solving is not carried out in isolation. There are multiple factors including the learning environment and the pedagogical approaches incorporated when delivering problem solving learning activities.

Challenges to the incorporation of ICT in education have been observed. Among the challenges, curriculum constraints, limited time and resources are common difficulties that teachers encounter (McGarr, 2009) (Kim & Hannafin, 2011)(Sun, Looi, & Xie, 2014). Hoyles (2016), highlights that use of technology may not be reaching its intended potential in classrooms and argues multiple factors must be included in order to get the most from the technology.

Similar with the growth of ICT in society and education, questions regarding a reform of how education is delivered have been discussed. Fadel (2015) (Centre of Curriculum Design) stresses the necessity to revitalise the educational experience. Similar to Fullan & Langworthy, Fadel affirms the importance of establishing the "4c's of creativity, critical thinking, communication and collaboration" as integral aspects to any educational experience (Fadel, 2015, p. 2). In addition, the European Union has highlighted that all citizens should have the opportunity to develop higher order skills including problem solving skills and digital skills (Commission, 2002).

In 2008, in Ireland a new mathematical curriculum (Project Maths) was established. The goals and aspirations of the new syllabus have common similarities to modern mathematical curriculums being established internationally (Dossey, Halvorsen, & Sharon, 2012), (Hoyles, 2016). An increased emphasis is placed on developing the depth of student understanding of mathematical models and concepts, though the application of contexts that students can relate to. It follows, that developing problem solving skills is an underlying goal of Project Maths (Jeffes et al., 2013), (Grannell, Barry, Cronin, Holland, & Hurley, 2011), (Lubienski, 2011).

Similar to the transformations of mathematical teaching and learning in Ireland, 2011 saw the introduction of a revised Junior Cycle Framework for all subjects at Junior Certificate Level. The NCCA (2011) established a new educational framework, similar to international trends on modernising the educational experience and preparing students for the 21st century (NCCA, 2014), (Fadel, 2015). In addition to Project Maths this framework confirms an importance to facilitating the developing of problem solving skills across all educational contexts.

2.3 Problem Solving Strategies

Numerous definitions of problem solving have been reported in the literature. Problem solving is referred to the process of investigating open or closed ended questions, sometimes involving complex calculations with the use of higher order skills with varying degrees of difficulty (Leong et al., 2012), (Polya, 1981). Furthermore, analysing the literature it is clear that when involved in the problem solving process, the learner is required to think, plan, analyse, test and reflect when addressing any problem (Montague, Krawec, Enders, & Dietz, 2014), (Resnick & Glaser, 1976) (Polya, 1981)(Kim & Hannafin, 2011), (F. Lester, 2016), (Gok, 2015), (Stevenson, 1925). Additionally, the problem solving process develops the learner’s ability to be able to synthesise and analyse the problem which will develop in a deeper learning process for the student (Leong et al., 2012), (Polya, 1981). The ability for a student to use spatial visualisation, reflect on past dispositions including knowledge, background and to decode the inherent features of a problem highlight the difficulties that students encounter when problem solving (F. Lester, 2016).

Schoenfelds (2007) meta-analysis on problem solving research highlighted that, problem solving was a major focus of mathematics education research in the United States over the past 30 years. The research discusses various opinions on the design of alternate curriculums that allow for adequate levels of problem solving to be taught and how to successfully deliver them. Despite the magnitude of research conducted, problem solving is widely regarded as a difficult concept to understand (Jeffes et al., 2013). The range of skills required including, abstraction, problem decomposition and the higher order thinking required have all been highlighted as difficult skills to master when problem solving.

The seminal work from Polya (1945) on problem solving strategies led to the development of an initial four-step problem solving strategy. Polya’s initial four-step model guides the students through a process that requires the student to “understand the problem; devise a plan, carry out the plan; and look back” (Polya, 1945). Polya argued that developing metacognitive awareness within students when tackling problems is important. Furthermore, establishing a reflective process while problem solving will allow the learner to review the skills applied and consider if this skills could be transferrable and applicable to problem solving in any context (Leong et al., 2012).

Based on the work of Poyla, numerous researchers have tried to develop their own set of heuristics for problem solving. Resnick & Glaser (1976) established a three stage model "problem detection, feature scanning and goal analysis" to guide the student through the problem solving process. Similar to Polya's model, Resnick and Glaser emphasise that problem solving is an irritive process that involves multiple irritations that are not always linear. The process requires the learner to constantly evaluate and analyse the reasons for their decisions (Resnick & Glaser, 1976).

Another significant problem solving model that is referenced in the literature is the six step model created by Treffinger and Isaken (1985) established as part of their research on Creative Problem Solvers (CPS). Version 6 of the CPS model includes a six step process of "identification, collection of data, formulating a problem statement, constructing an idea, finding a solution and evaluation of the solution" (Treffinger & Isaksen, 2005). Inherent to the model is the underlying principle for teachers to "teach thinking skills" and train the students to monitor and reflect on their progress when attempting to problem solve. A key component to the design of this model is based on how people behave naturally, i.e. Treffinger and Isaken argue that problem-solving strategies need to be flexible and dynamic so that people can apply the model in a range of contexts.

In contrast to Treffinger and Isakens model, Schoenfelds (1985) problem solving strategy operates on the principle of a checklist to verify all viewpoints have been considered before moving on to the next stage. Schoenfelds highlights, the transition between each stage in the strategy is vital to successful problem solving, arguing that students can often skip steps and become frustrated when problem solving (Schoenfeld, 1985). In this strategy, steps are described as a series of episodes including, "analysis, reading, planning, exploration, implementation and verification" (Schoenfeld, 1985)(Lester et al., 1989).

The above are just a sample of the problem solving strategies that have applied in the teaching and learning of problem solving. This dissertation investigates the design of SPSM to investigate impact on developing student's metacognitive skills while problem solving. In Chapter 3, the merits and a critique of each of the models is presented and a discussion on how this informed the design of the new SPSM is outlined.

2.4 Computational Thinking Strategies

Research on CT is relativity new and research into the application of CT in mainstream education is limited. Originating form practices in computing in computer science, Wing (2006) defined CT as the mental process involved when solving problems and computing (Wing, 2006). Wing (2006) outlines there are four major components involved in CT, "Decomposition, Pattern recognition, Abstraction, Algorithm Design". These skills are similar to the skills outlined by Polya et al when attempting to problem solve.

Furthermore, the National Research Council in USA (NRC) (2010) highlights that CT encourages the learner to practice skills such as abstraction, decomposition, simulation, problem representation, verification and prediction (National Research Council , 2010, p. 592).

In 2016, Kalelioglu, Gulbahae & Kukul (2016) established a computational thinking framework as a problem solving process (Kalelioglu et al., 2016). Their framework establishes a 5 step problem solving process under the foundations of the computational thinking genre. These steps include "identifying the problem, gathering, representing and analysing data, generate plans, implement solutions and assessing solutions" (Kalelioglu et al., 2016, p. 545). Inherent to the model is the use of computers to improve problem solving and critical thinking by harnessing the affordances of computing (International Society for Technology in Education (ISTE) & Computer Science Teachers Association (CSTA), 2011). The use of CT thinking in mainstream education is focused on developing the relationship between the use of technology in education and preparing the student cohort for the 21st century.

Figure 1: Framework for Computational Thinking as a Problem Solving Process

Identify the problem	**Gathering, representing and analysing data**	**Generate, select and plan solutions**	**Implement solutions**	**Assessing solutions and continue for improvement**
Abstraction (3) Decomposition (3)	Data collection (2) Data analysis (3) Pattern recognition (1) Conceptualising (1) Data representation (2)	Mathematical reasoning (1) Building algorithms and procedures (3) Parallelisation (2)	Automation (3) Modelling and simulations (3)	Testing (1) Debugging (1) Generalisation (1)

In addition, CT requires the student to perform higher level thinking skills, such as algorithmic thinking, compositional reasoning, pattern recognition and recursive thinking that will result in a deeper learning process, hence engaging the student in the learning activity and enhancing their learning (Wing, 2006)(Fullan & Langworthy, 2014)(ISTE & CSTA, 2011).

2.5 Metacognitive Skills in Problem Solving

Having considered the literature on developing problem solving skills and strategies, it is also important to discuss the role of metacognition in mathematical problem solving. An important feature that effects problem solving skills is the student's predisposition and metacognitive beliefs about problem solving. These attitudes and beliefs can have positive and negative effects on the processes involved during problem solving (F. K. Lester et al., 1989).

Initial definitions from Flavell (1979) and Brown (1978) define metacognition as one's knowledge and understanding about their cognitive activities in a learning activity. (Brown, 1978) (Flavell, 1979). Common terms associated with metacognition include, metacognition beliefs, metacognitive skills and metacognitive experiences (Veenman, Van Hout-Wolters, & Afflerbach, 2006). Research has indicated that the development of metacognitive skills can influence a person's procedural knowledge in the problem solving process (Veenman et al., 2006).

In Addition, Veenman et al (2006) conducted a study to investigate the importance of metacognitive skills when problem solving. The study highlighted the important role the use of metacognitive skills can have when problem solving. The investigation emphiased the positive effect the use of the "WWW&H rule, What to do, When, Why and How" can be on developing students metacognitive skills. (Veenman et al, 2006, p.9)

Furthermore, research from Bandura (1989) has emphasised that effective cognitive behaviour skills can be modelled from teachers, peers and parents, where students can observe and inherent these skills. Similar to Vygotsky's theory on the zone of proximal development (Vygotsky,1978), the advantages of learning in collaborative environments with more able others can enhance the process of learning (Harland, 2003). The role of the teacher in creating learning environments that allow for effective problem solving is important. Lester et al's (1989) research argued that students will have difficulty in becoming proficient problem solvers unless ample opportunity is given to them with carefully constructed problems that allow students to apply higher level thinking skills. Consequently, designing a functional mathematical curriculum has an important impact on the success of developing effective problem solvers. Developing problem solving skills does not take place in isolation. There are numerous factors that affect the development of these skills including; the design of the learning environment and the pedagogy used to develop these skills.

Given the advantages of developing metacognitive skills, it is important for educators to be able to analyse if metacognitive skills are being successfully utilised in problem solving situation. Kroll (1988) established a framework to monitor the behaviour and roles of students in collaborative problem solving environments. The plan consists of a four step checklist to assess if students utilised their metacognitive skills. Firstly, it provides an analysis of what strategic behaviour was used to understand the problem. Secondly, what planning behaviour was exhibited when deciphering the problem? Thirdly, in the execution of their plan did the students monitor and regulate their idea to conform to the initial plan and finally, is there indication of evaluation or verification of their outcomes.

Research into why students have difficulty when problem solving has revealed that in order to be successful at problem solving, one is required to engage in various cognitive actions at the one time, some of which requires skills and knowledge that are not routinely used (Veenman et al., 2006). Similarly, Lester et al (1987) outlined that "knowledge, control, affects, beliefs and contextual factors" can impinge on the development of a successful problem solver (Lester et al., 1989, p3). Evidently, some of the variables that affect students are difficult to control or dictate, however establishing effective learning environments that can foster effective problem solving and can decrease these effects is important. Training students to "control" their metacognitive processes could result in students becoming more effective problem solvers.

Similarly, creating problem solving environments where students can contextualise and bring real world knowledge to the problem can have positive impacts. The design of the learning environments that allow students to use their higher order thinking skills are fundamental to teaching and learning of problem solving and the importance of curriculum design (Fullan & Langworthy, 2014) (Pence, 2010) (Fredricks et al., 2011) (Cooper & Sandi-Urena, 2009)

In this manner the importance of the Realistic Maths Education (RME) Programme established in the Freudenthal Institute in the Netherlands can be seen. This pedagogy known as "Maths in Context" encourages students to apply their experiences, intuitions and commons sense to develop their mathematical knowledge and problem solving skills (Freudenthal, 1991).

Today in the Irish context, the introduction of Project Maths has similar aims to the RME programme but has had a mixed response from teachers and students. Overall reports have indicated the level of student performance is increasing (Jeffes et al., 2013), however teachers have expressed concerns including time constraints, their level of competence and knowledge in designing and organising effective problem solving lessons (Grannell et al., 2011). There are numerous factors to be considered when developing problem-solving skills. One factor is the creative effective learning environments. However, creating a suitable learning environment that can allow for higher level thinking that allows for collaboration and development of metacognitive skills in a didactic traditional classroom can be difficult (Conneely et al., 2012).

2.6 Pedagogical Approach:

Given the literature presented on effective problem solving and developing metacognitive awareness it is important that an effective pedagogical approach is incorporated in the teaching and learning of problem solving. Promoting an active learning process where the student is centre to the learning activity, where the student is encouraged to critically think and reflect thus exhibiting higher order thinking skills has been proven beneficial (Fullan & Langworthy, 2014) (Gok, 2015) (Handelsman et al., 2005).

For these reasons, the cognitive pedagogical frameworks of social constructivism and constructionism were reviewed. Firstly, the social constructivism pedagogy was established from the work of Piaget et al (1985), Vygosky (1978) and Papert (1981) which postulated that successful learning environments are established as a result of social activity. An emphasis on the importance of communication and collaboration between students in learning environments was stressed. Piaget reported that the acquisition of knowledge is developed within the interaction of people and the world around them (Piaget, 1955),(Ackermann, 2001). With equal importance, Piaget argued that a significant factor that takes place in learning is the importance of prior knowledge and understanding that the learner can relate to when creating new meaning. (Piaget & Inhelder, 1967)

Vygotsky's work highlights the advantages of collaboration and communication between learners. In particular, his theory on the Zone of Proximal Development (ZPD) states that interaction between peers as an effective method of enhancing learning environments. In terms of problem solving Vygotsky discussed the limits to independent problem solving in comparison with collaborative peer problem solving approaches with adult guidance and argued that creation of knowledge can be more beneficial when multiple perspectives are considered (Vygotsky, 1978)(Kim & Hannafin, 2011). Learning that takes place as result of learning from more abled others will not only result in more effective learning, it can allow students to appreciate and discuss multiple opinions, strategies, and conceptualisations when problem solving.

Similarly, Papert's constructionist pedagogical framework argues the benefits of student centred learning environments. In contrast however, constructionism argues that for successful learning to take place the creation of artefacts in the learning activity should be present (Papert, 1980). Here the learners not only create new knowledge, they also create physical or visual artefacts that represent and convey that knowledge. Jonassen & Carr (2000) advocate that these artefacts allow for the student to represent their internal representations externally. Furthermore, the learners can use these artefacts to communicate, demonstrate and collaborate their knowledge with others.

In addition, Papert highlighted the importance of context, student attitudes and learning styles when creating and designing effective learning environments. In accordance with research conducted by Kim & Hannifin (2011) and Bray and Tagney (2015) the role of establishing effective learning environments highlights the important role that the teachers have in establishing the effective problem solving activities. Establishing innovate learning practices changes students from just being receivers of information without any input, into constructors of knowledge that has personal meaning (Voogt & Pelgrum, 2005).

Transitioning from the 20th to the 21st century in the approaches one applies to develop problem solving skills is important. Dede (2010) highlights that problem solving can no longer be presented as an abstract process with a set of prescribed skills. Furthermore, problem solving must be taught to develop and enhance metacognitive strategies and decision making so that they can be applied when no standard solution is evident. Kim and Hannifin (2011) highlight successful evidence to support student's problem solving with technology enhanced learning environments has been scarce. Thus in order incorporate suitable pedagogies with technology a suitable learning framework is required.

Imperative to this research investigation is the design of the learning experience to allow students develop their problem solving skills. Jonassen (1999) maintains that the success of meaningful learning relies of the depth of engagement the learner exhibits with the problem and the relationship the student develops with the problem. The design of the problems is important to insure that the problems are interesting and complex enough to capture the curiosity of the learner.

2.7 Role of Technology

Having considered appropriate pedagogies to encourage active learning and student centred learning, it is also reasonable to discuss the role technology can effect in creating deeper learning environments. Li & MA (2010) have noted that the traditional use of instructional technologies as means of transmitting and sharing information with students is no longer sufficient.

As a result of the growing domain of ICT in society, society now has access to a range of technologies that enable them to interact, analyse, manipulate, explore, evaluate and represent information in multiple forms (Voogt & Pelgrum, 2005). Improving student attitudes and beliefs, the teaching and learning of maths, presenting underlying concepts, relationships and structures in maths are some of the areas that technology could potentially assist in (Bray & Tangney, 2016). Hoyle (2016) argues that the use of technology as a mathematical lens can assist students in making maths more visible and easier to comprehend.

Bray (2016) conducted a systematic review on the current trends of technology in Maths education. She argues that cognitive learning theories of Constructivist, Social Constructivist and Constructionist where most commonly used with the incorporation of technology. Bray & Tangney (2015) highlighted that teachers where using the technology for a range of purposes including “developing attitudes, collaboration, to improve conceptual understanding, performance and skills focused” (Bray & Tangney, p. 11). The study highlights the affordances of technology to enhance the learning experience for students by constructing and investigating mathematical models through technology.

However, research has indicated that the successful incorporation of technology in education has yet to reach its potential. Unless the incorporation of appropriate pedagogies in a suitable scaffolded learning environment is established much of the potential of technology is not being harnessed (Conneely et al., 2012)(Bray & Tangney, 2015)(Fullan & Langworthy, 2013)(Kim & Hannafin, 2011). Plausible reasons to explain why technology has not been as successful at is should be include, teachers level of competence and beliefs about technology, curriculum constraints and inadequate continual professional development provided to teachers on the use of technology (Olive et al., 2009)(McGarr, 2009)(Voogt & Pelgrum, 2005) (Siddiq, Scherer, & Tondeur, 2016).

Hoyle (2016) characterised the affordances of technology for Maths under the following headings, “dynamic & visual tools, exploratory environments, connectivity and collaboration and processing power. Technology that is dynamic, interactive and graphical can allow students to explore mathematical objects from various perspectives. Hoyle states that the technology can enable to students make “explicit that which is implicit, and draw attention to that which is often left unnoticed” (Noss & Hoyles , 1996, p. 65). This is particularly highlighted in research in engineering education. Fang & Guo (2016) contend that the advantages of students being able to visualise the spatial movement of a mechanical system allows for a greater understanding of relationships and structures that exist in the movement in systems.

Studies conducted by Martinez et al (2011) emphasise similar advantages on the use of technology in representing abstract topics in physics. Specifically, in maths education, the use of technology in the teaching and learning of Geometry, Sequences and Series, Functions and Algebra can all be taught using a dynamic representational software such as Geogebra. Here the technology has the capacity to connect the learner to the context of the learning environment where students can test, implement and reflect on their ideas to create meaning and develop understanding (Olive et al., 2009).

A dynamic, interactive, and exploratory learning environment can be described as a Microworld. (Rieber , 2005). Similarly, diSessa (2000) defined the best Microworlds are those that are easy to use and engage students in a series of tasks that result in the student developing an understanding of the underlying principles. Edwards (1995) defined Mathematical Microworlds as (1) models that represent mathematical properties, (2) allow for multiple representations of the model and (3) allows for interaction and exploration of the mathematical model. The use of Microworlds to develop conceptual understating of topics has been reported. Research from Winn et al (2006) highlighted the affordances of Microworlds to develop student’s deeper understanding of the phenomena and the relationships between variables. Rieber (2005), argues that the best Microworlds have a multiple range of operations that are easy to understand and engage the student to discover the underlying principles of the topic

Having considered the advantages of technology in education, it is also reasonable to consider a model to rationalise the role of the technology in the learning activity. The

SAMR (Substitution, Augmentation, Modification and Redefinition) model designed by Puentedra (2006) is a framework that can be used by educators to classify the purpose of the technology in the learning environment. The model categorises the use of technology under four headings. The transformation stage categorises technology that is used to create and represent tasks that would not be possible without the use of technology (Romrell, Kidder, & Wood, 2014). This type of technology is described as modifying or redefining the learning experience. Bray (2016) highlights positive results can be seen, if the incorporation of technology at the transformation level is combined in a 21st century learning environment to maximise the potential of technology (Fullan & Langworthy, 2014)(Bray & Tangney, 2015).

2.8 21st Century Learning Model

Internationally and nationally discussions our taking place about a necessity to revitalise the education system worldwide due to development of the digital revolution and the modern demands expected from our students, (Fullan & Langworthy, 2014)(Pence, 2010)(Dede, 2010). 21st century teaching and learning frameworks are designed to prepare students to meet these modern demands. Frameworks such as P21 (Partnership for 21st Century Learning, 2014) and Bridge 21 (Conneely et al., 2012) and Microsoft's 21CLD (Microsoft, 2014) are some of the frameworks designed at promoting 21st century learning. Voogt and Roblin (2012) identified that establishing learning environments that promote creativity, problem solving and critical thinking were essential to creating a 21st century learning environment.

2.8.1 Bridge 21 Learning Framework

One 21st century learning model that facilitates for the development of such 21st century skills is the Bridge 21 model. The model was developed in Trinity College Dublin and focuses on the development of 21st century skills with the incorporation of technology. Fundamental to the model is designing learning activities that allow for student centred activities where the teacher scaffolds the learning (Conneely et al., 2012). The model has been specifically proven to promote and develop student engagement and participation with the use of digital media in maths education (Tangney & Bray, 2006)(Bray, Tangney, & Oldham, 2013).

Another significant feature of the model is the role of the teacher. A shift from the traditional didactic teaching methods is replaced with the teacher scaffolding the learning experience. Scaffolding, in this context, is a method through which more knowledgeable others (teachers or fellow students) provide cognitive and social supports designed to develop and enhance student problem solving skills (Kim & Hannafin, 2011). The students take a more active role in the learning environment, where students are responsible for the creation and presentation of their work (Conneely et al., 2012).

The Bridge 21 learning model has been used to create innovative learning experiences with the use of technology (at the modification and & redefinition level of the SAMR framework) across a range of subjects including, maths, coding, languages and physics. (Conneely et al., 2012) (Tangney et al., 2015). The Bridge 21 model encourages the use of group work to promote student involvement and motivation in learning activities. The model has been proven to promote intrinsic motivation and enhance student engagement (Lawlor, Marshall , & Tangney, 2015).

2.9 Conclusion

This literature review has presented some of the challenges associated with developing successful problem solvers. The review has highlighted that developing problem solving skills is an underlying goal of many mathematical curriculums. The process of problem solving is a complex process that relies on numerous factors which impinge on the success of developing successful problem solvers. Some of the variables are not controllable by the teacher, such as background and knowledge, however attitudes beliefs and control can all be developed if a successful problem solving environment is established.

Thus how to create these learning environments is the elusive goal for educators. A discussion on current problem solving strategies was investigated and a comparison between these models and computation thinking strategies was assessed. The importance of developing metacognitive skills was significantly highlighted in the literature, which is emphasised in the discussions on how to prepare students for the 21st century.

In addition, a discussion on the incorporation of cognitive learning pedagogies was presented. Research has highlighted that use of social constructivism and constructionists learning approaches can result in increasing student engagement and activity in learning environments. Similarly, the role of technology in developing problem solving skills was examined. The use of Microworlds to develop critical thinking and problem solving skills was identified.

Finally, for the incorporation of technology with cognitive pedagogies to be successful an analysis on 21st century learning frameworks was presented. The affordances and research presented on the Bridge 21 learning model to successfully develop 21st century skills, reveal a shift from the traditional learning environment is required in order to create these suitable learning environments. Developing problem solving skills is a complex and difficult process. The pedagogical approach and design of the learning environment are important factors to be considered. This literature review has informed the design of the learning experience to investigate the use of the SPSM to develop students metacognitive skills while problem solving.

Chapter 3: Design

3.1 Introduction

Chapter 2 discussed some of the research conducted on developing problem solving skills. Problem solving is a complex and difficult process that requires the student to apply multiple skills. Various overlapping heuristics for problem solving were identified. The design of the SPSM was developed by the researcher to help students develop their metacognitive skills (planning, monitoring, reflecting) when problem solving. The new SPSM synthesises the heuristics outlined in other models and presents the steps required when problem solving in a model that the students can relate to and understand.

Problem solving is not taught in isolation. Numerous factors should be considered when designing effective learning environments that allow for the development of these skills. There is a strong argument for situating problem solving in a 21st century paradigm, and this is evident in Ireland with the introduction the new Junior Cycle and the introduction of Project Maths. The literature review highlighted the potential influence that ICT, specifically simulations and Microworlds can have on redefining the learning experience. In addition, the affordances on technology when combined with a 21st century learning framework were presented.

This research created a set of synthesised heuristics on problem solving and tested there effectiveness in a number of learning experiences designed in accordance with the five key design principles. The foundations for the design of the learning experience in this study are established on five main criteria:

1) The Pedagogy, 2) The Problem-Solving Model, 3) The Role of Metacognition,
4) The Inclusion of Technology, 5) A 21st Century Learning framework

The design of a 21st century learning environment provides the foundations for this study. Creating learning environments where students are active participants, where they can construct knowledge and express their levels of understanding by applying their higher order skills when problem solving is important. This dissertation will examine the effect of a Microworld simulation to redefine the learning experience where students can actively engage with problem solving and display their creativity and critical analysis when problem solving.

The design of the learning intervention in this study is designed to investigate the following research questions:

> *Q1. Does the use of the SPSM, enhance problem solving skills and metacognitive skills when problem solving.*
>
> *Q2. Sub Question: What role/impact did the Microworld simulation have in the process?*
>
> *Q3. Sub Question: What role did the Bridge 21 learning environment have in the process?*

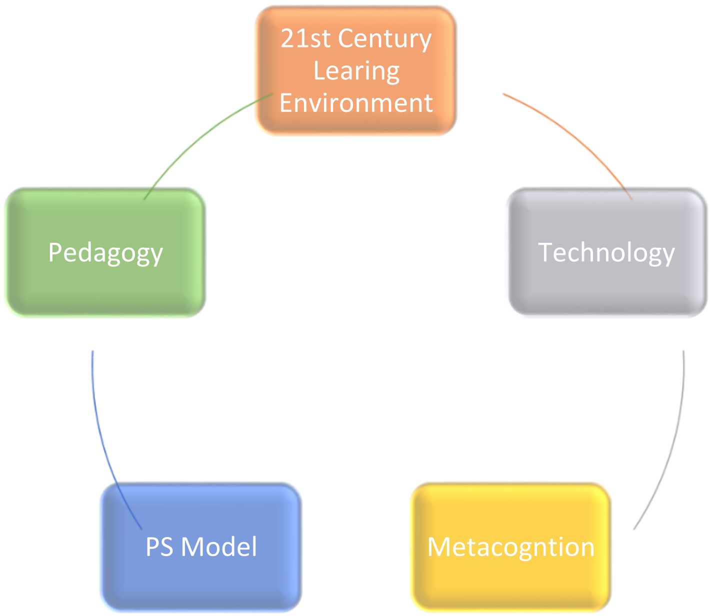
This chapter will discuss the design of the learning activity used in the study to investigate if the incorporation of a SPSM combined with a 21st century learning experience can affect the development of metacognitive and problem solving skills while problem solving. Problem solving is not taught in isolation, this study will investigate the merits of the design of the learning activity to develop these skills.

3.2 Design Framework

3.2.1 Design of Learning Intervention

The literature review not only provided an insight into the research conducted in problem solving thus far, it informed the design and construction of the learning activity for this case study. The five categories that underpin the learning experience are outlined in figure 3-1.

Figure 2: Overview of the design framework informed by the Literature Review



The learning experience is constructed upon the foundations of two main pedagogical models of Constructivism (Piaget,1980) and Constructionist (Papert, 1991). Both models refer to the process of learning in a social context and reinforce that learning is most beneficial when learners are working in a collaborative environment. In addition, research has highlighted the positive effects on student engagement and participation when an elements of Papert's Constructionism are incorporated in the learning activity (Wickham, Girvan, & Tangney , 2016), (Bray & Tangney, 2015). Evidence suggested that higher levels of conceptual learning and engagement are evident if the students are actively creating, designing and constructing artefacts that represent their learning in the learning activity.

The literature review also highlighted numerous problem solving models that are established to support learners while problem solving. A model of problem solving synthesised form the current and past approaches was created with reference to the literature for the learning intervention. The researcher decided to design a synthesised problem-solving model that was easy for the students understand and guided students through the problem solving process. The researcher decided that more support is needed in guiding students through the steps of "Plan, Create, Design, and Reflect" when problem solving. The model breaks each of the steps into more detailed steps that students should considered when problem solving. Inherent to the design is the steps that students can take to use their metacognitive skills of planning, monitoring and reflection while problem solving.

The importance of metacognition while problem solving was also emphasised. The essence of developing metacognitive skills when problem solving will prepare the learner for "what to do, when you don't know what to do" (Cooper & Sandi-Urena, 2009, p. 244). Developing ones metacognitive skills, in particular their "planning, monitoring and evaluation" whilst problem solving can lead to creating more efficient problem solvers.

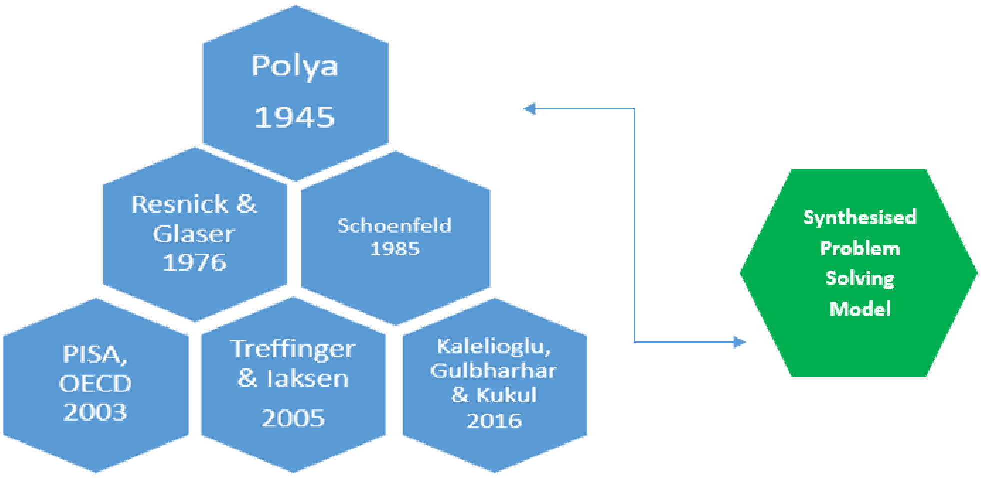
In addition, the literature review highlighted the potential benefits to the incorporation of technology in education. The affordances of technology to transform and redefine the learning experience so that they could interact with and investigate the underlying principles and relationships in a topic was highlighted. A particular Microworld simulation was selected based on its ability to allow students to interact with the software and allowed for the use of higher order thinking skills when problem solving.

Evidence in the literature review had highlighted for the successful incorporation of technology in the learning environment, was successful when introduced with cognitive learning approaches and a 21st century learning environments. The final component to the design intervention was the selection of an appropriate 21st century learning framework. The Bridge 21 learning model has been proven a suitable learning model to accommodate technology in a traditional classroom setting with research that highlights the potential benefits on increasing student motivation and engagement in 21st century learning activities (Lawlor, Marshall , & Tangney, 2015), (Tangney et al., 2015.).

A detailed summary table of the design of the learning experience with reference to the literature is attached in the appendices(1).

3.3 Design of Problem Solving Model.

Figure 3: Overview of the literature that informed the design of the SPSM



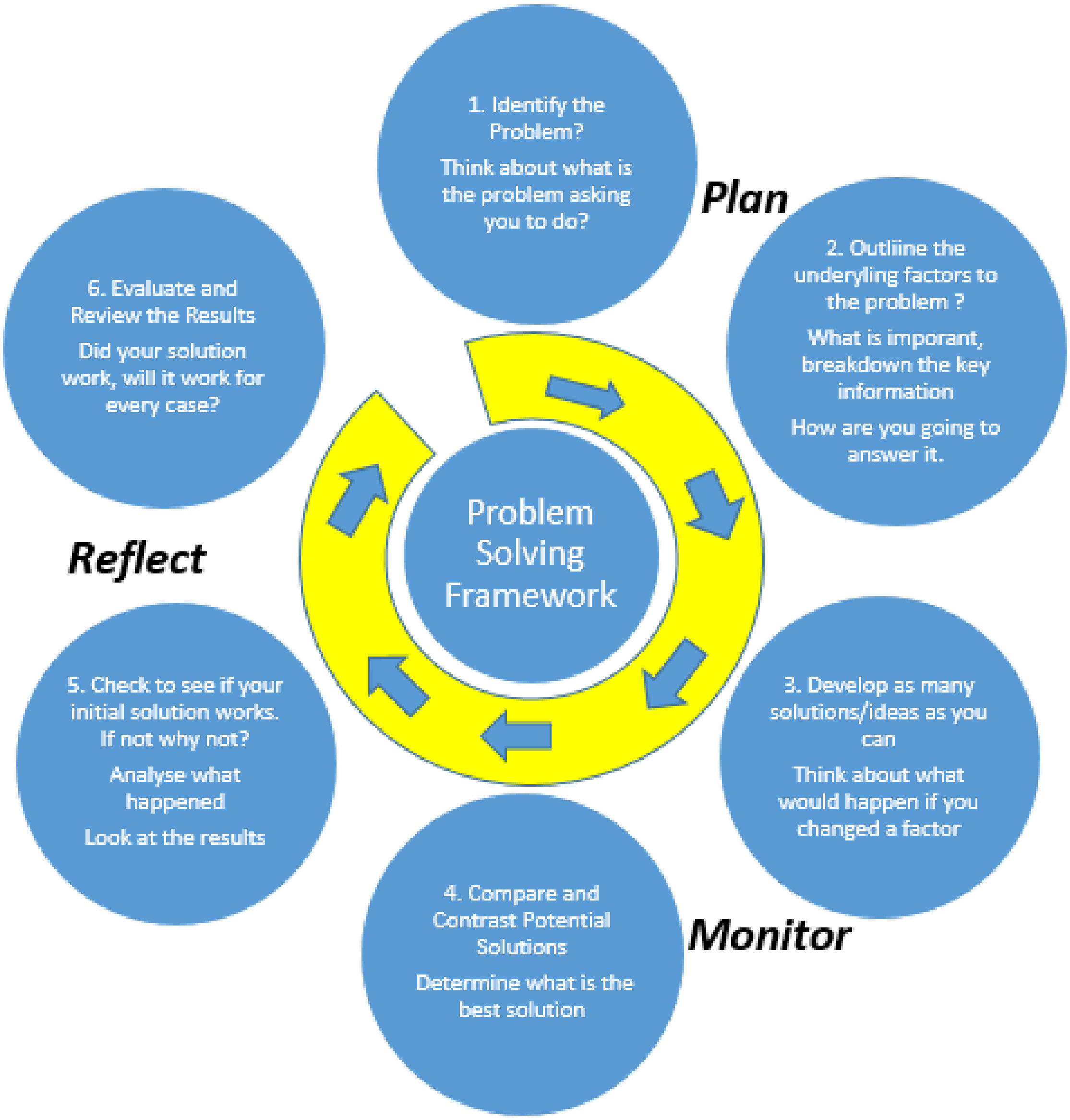
An equally significant aspect of developing efficient problem solving skills is the ability to use effective problem solving strategies. An analysis of existing problem solving models was conducted to focus on the essential elements that could develop students metacognitive skills while problem solving. Five problem-solving models and one computational thinking model were reviewed for the literature. This review informed the researcher on the design of the synthesised problem-solving model (SPSM). The table below highlights the main characteristics of each model.

Table 1: Analysis of Current PS Models.

Problem Solving Model	**Characteristics/Features**	**Critique / Comment**
➢ **(Polya, 1981)**	➢ 4 Step Model: "Understand the problem, Devise a plan, Carry out the plan, and look back"	➢ Guides the students through the problem solving process, however the steps are little vague. ➢ More clarity needed on how to approach each of the steps.
➢ **(Resnick & Glaser, 1976)**	➢ 3 Step Model: Problem Detection, Feature Scanning and Goal Analysis.	➢ Language may be difficult for students to comprehend or relate too. ➢ More steps required.
➢ **(Treffinger & Isaksen, 2005)**	➢ 6 Step Model: "Identification, Collection of Data, Formulating a Problem Statement, Constructing an Idea, Finding a Solution and Evaluation of the Solution"	➢ Very detailed model, which provides good clarity on how to deconstruct and create potential solutions. The model is an irritive cycle where one may have to repeat the steps.
➢ **Schoenfield (1985)**	➢ Steps involved when Problem solving: "Analysis, Reading, Planning, Exploration, Implementation and Verification"	➢ Steps accurately describe the metacognition involved when problem solving. ➢ More detail required to demonstrate how to complete each step.
➢ **Pisa (OECD, 2003)**	➢ 5 Stage Process: The Mathematisation Process	➢ Model describes the mathematical processes involved when problem solving. ➢ Language inappropriate for students
➢ (Kalelioglu et al., 2016)	➢ Computational Thinking Framework: "Identifying the Problem, Gathering, Representing and Analysing Data, Generate Plans, Implement Solutions and Assessing Solutions	➢ Very detailed model and takes into consideration the four main components on Computational thinking "Decomposition, Pattern recognition, Abstraction, Algorithm Design" which are all inherent to the problem solving process.

Each of these theoretical models make important contributions to design of the synthesised model. Inherent to an effective problem solving model is the ability to support students in planning, monitoring and evaluating their thought process while problem solving. The researcher created a synthesised problem-solving model that could support students with these skills and was easy to understand. The model insures that students remember to use their metacognitive skills when problem solving. Comparing Polya's 4-step model to the synthesised problem-solving model, the researcher decided to use six steps that breaks down the problem solving process into smaller steps. The rational for this was to insure that students used their metacognitive skills effectively in each step. Additionally breaking down the problem solving process into smaller steps could potentially make the problem solving process easier. The researcher designed the image of model so the students could understand the process looking at the image. Figure 3.4 represents the synthesised problem-solving model designed for this intervention.

Figure 3: The SPSM used in the Study



The design features of the model that differ from the current heuristics include:

- The model simplifies the steps of planning, monitoring and reflecting by highlight key steps to do at each stage.
- Each stage highlights important higher order skills the students can use when problem solving.
- The model emphasises the use of metacognitive skills when problem solving.
- The language used is student friendly so that students can easily understand the steps
- The design of the model is cyclic; to reinforce that students may have to repeat or revisit steps.

Problem solving can be difficult and this study investigates the use of this model (SPSM) on developing student's problem solving skills in a 21st century learning environment.

3.4 Implementation & Delivery

The learning activity was delivered to 21 Transition Year students (aged 14-16) in a post primary STEM club. The learning experience was tested over a 4 week period with the total learning experience lasting over 8 -10 hours, including six 40-minutes classes and three 80-minute classes and a pilot investigation.

An initial pilot intervention was delivered to 20 students of similar background to evaluate any potential problems that the students would encounter. The researcher evaluated the success of the Microworld selected and assessed if it matched the criteria established in this chapter. A review of the e-learning tool (website) and the open and closed problem solving questions that were used in the learning activity.

The researcher decided to deliver the learning experience to another set of participants to investigate if there was any differences in delivering the learning experience to a younger cohort. Eighteen students participated in the study and qualitative data was collected from this group with a focus group interview.

3.5 Topic

The topic to be investigated by the participants in the case study is not considered a variable in the research. However when designing the learning activities, consideration was given to the levels of prior knowledge, and topics that would require a high level of problem solving. The instructional goal of the learning experiences are to develop and enhance student's problem solving skills and strategies. Two topics were selected for this investigation. The topics were selected on the basis of prior knowledge and the level of problem solving required in each topic.

The first topic decided upon was problem solving through bridge design and a detailed lesson plan of the learning activity is attached in the appendices (2). A website was designed to scaffold the learning experience for the students. The website provides a detailed description of the open and closed problem solving questions that students had to answer in the learning activity, http://bridgedesignproblemsolving.weebly.com/ . Students are required to construct, design, analyse and review a series of bridges to insure that each bridge meets the specific criteria. Students must use their problem solving skills to analyse the structural integrity, design of the bridge and assess if the bridge is cost effective.

This topic was selected for the following reasons:

- Students in the study, have no prior knowledge in bridge design.
- Bridge design can require a high degree of creativity, critical and problem solving. The topic will require the students to use their metacognitive skills when problem solving.
- The topic requires students to use a high level of mathematics and physics. Students must analyse, compare and contrast the fundamental forces exerted on a load carrying bridge.

This topic was the primary learning experience in this investigation. The majority of the data collection and analysis was used to gather data on impact this learning intervention.

A second topic was chosen that was delivered to assess the students problem solving skills in the use of an alternative Microworld. A series of puzzles and mazes were used from the website https://blockly-games.appspot.com/ to assess the effect of the SPSM in another context and leaning environment. Students are required to use their problem solving skills to design the correct code to complete the puzzle. This Microworld allows the students to design and test solution to each problem. This topic was used as a warm up exercise to get students use to using the SPSM.

3.6 Bridge Design Software 2016

The selection of a suitable Microworld for the intervention was important when the designing the learning activity. Five factors where considered important to ensure the Microworld was suitable. The criteria were selected to insure that students could apply their higher order skills while problem solving and that the Microworld allowed the students to construct their own knowledge in the learning experience. The researcher analysed various Microworlds against the criteria.

Table 2: Criteria for Section of Technology.

Factors/ Criteria	Comments/Questions
Problem Solving & Critically Thinking	➢ Does the software require the students to problem solve? ➢ What types of problem solving activities (open/closed problems) can be created. ➢ Can the students apply problem-solving strategies to the problems presented?
Appearance/ Functions	➢ Does the Microworld provide a realistic representation of the problem? ➢ What is the range of functions in the software to allow the students to adjust the parameters and variables? ➢ Can the students test their ideas/solutions
Level of Constructionism	➢ Can the students construct artefacts that will represents their solutions to the problems? ➢ What level of constructionism is available?
Ease of Use	➢ Is the software suitable for the students? ➢ What platform can the software be used on?
Cost	➢ Does the Microworld Cost?

The table below shows some of the Microworlds reviewed and the rational for selection.

Table 3: Table of Microworlds Reviewed

Microworld	Comment/Criteria
WestPoint Bridge Designer **http://bridgecontest.org/resources/download/**	➢ Cost: Free ➢ User Friendly ➢ High degree of Constructionism available ➢ Low floor high ceiling Microworld ➢ Easy use of higher order skills including creativity, and critical analysis. ➢ Material not to advanced
Autodesk Structural Bridge Design **http://www.autodesk.com/products/structural-bridge-design/overview**	➢ Cost: not free ➢ Material to advanced ➢ Not user friendly for students ➢ Too difficult to design bridges ➢ Load Test too difficult for analysing bridge design
CSI Bridge Design **https://www.csiamerica.com/products/csibridge**	➢ Cost: not free ➢ Material to advanced ➢ Not user friendly for students
Civil Bridge Design **http://en.midasuser.com/product/civil_overview.asp**	➢ Cost: not free ➢ Too difficult to change bridge design ➢ Material to advanced ➢ Not user friendly for students

The Microworld selected is the Bridge Designer software 2016. The US Military Academy at West Point University developed this free educational software package. The software is designed to provide primary and post-primary students with a realistic and contextualised introduction to the fundamental principles of bridge design and construction. The simulation software is available to download for desktop for both Microsoft Windows and Macintosh Devices.

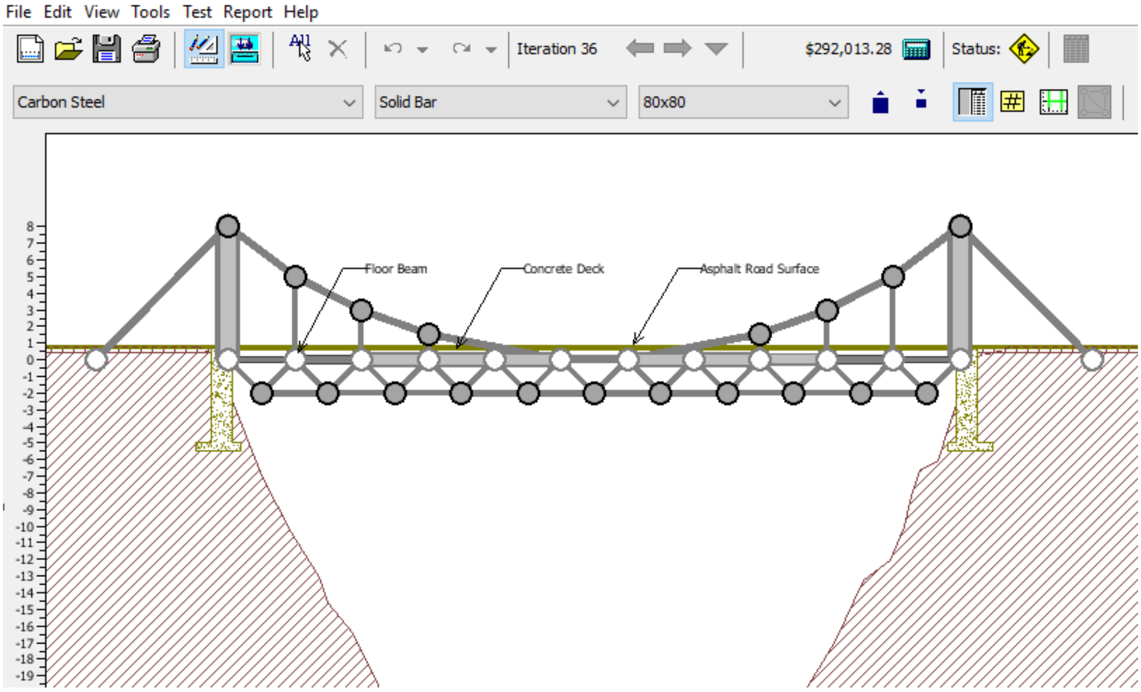
The software efficiently allows the participant to interact and manipulate important variables of bridge design and provides a realistic 3D simulation that can test the designs of the structures that are created. The affordances of the software allows the students to critically analyse and create innovative solutions that can be reviewed and evaluated. The software is in the redefinition and modification classification of the SAMR model and allows for transformation of the learning experience.

The Bridge Design Software accurately represents the mathematics and physics behind bridge design allowing the students to discover the fundamental forces of compression and tension that are exerted on the structure of a bridge. Students have the ability to analyse and investigate the load test results applied on each member and joint in the structure. Subsequently students can freely adjust the parameters in the structure and clearly view the impact of these changes.

In particular, the software accurately takes into consideration three fundamental concepts of Bridge design in the real world including; the design, structural integrity and cost. This low-floor high ceiling software allows for a range of bridge designs to be created. A built in cost calculations report provides an authentic representation to the costs associated with bridge design and construction.

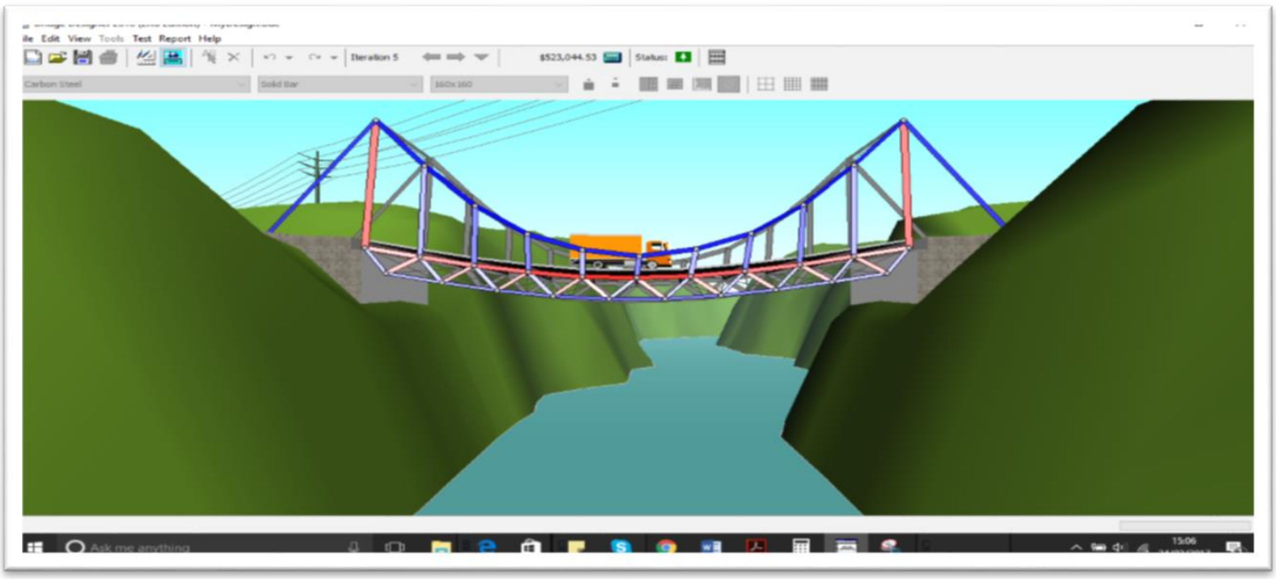
The high levels of constructionism in the software allows for the students use their creativity to apply innovative solutions to real world applicable problems in an engaging and exciting learning activity.

Figure 4: Image of Interface Design Stage of Bridge



The interface provides the user with a realistic model of their design. Each member is load tested for compression and tensile forces that it would experience. Interface is easy to understand and is user friendly.

Figure 5: Bridge Design Test. A simulation of the bridge design



The software allows the user to test and evaluate the success of the bridge by analysing the loads exerted on the members as the tuck passes over the bridge. Users and provided with instant feedback on the forces exerted by analysing the strength of the colour of each member.

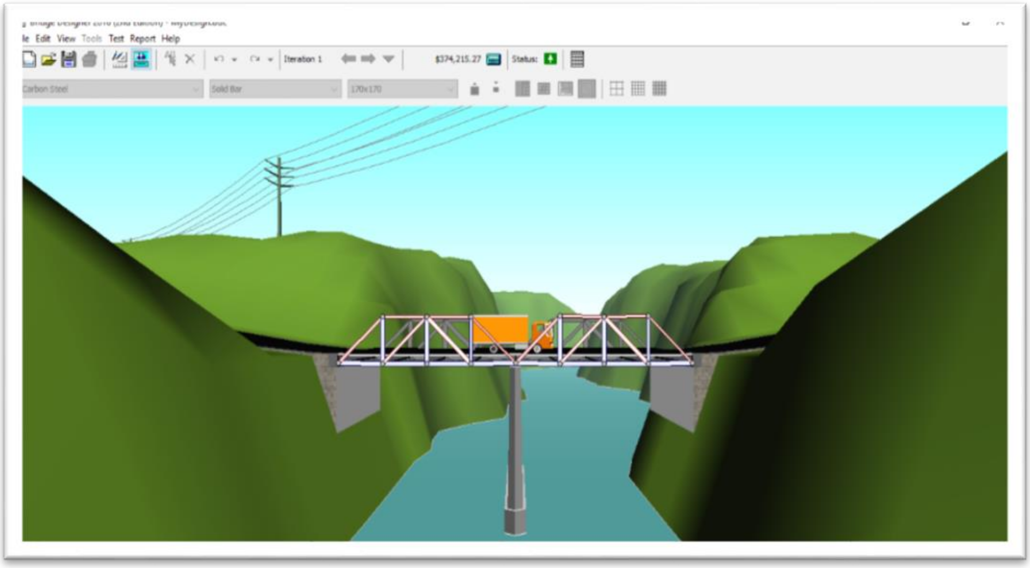
Figure 6: Image of Cost Calculations Report Produced

Cost Calculations Report

Type of Cost	Item	Cost Calculation	Cost
Connection Cost (C)		(34 Joints) x (400.0 per joint) x (2 Trusses) =	$27,200.00
Product Cost (P)	9 - 50x50 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	6 - 70x70 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 75x75 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 80x80 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 100x100 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	39 - 160x160 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 280x280 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,400 cubic meters) x ($1.00 per cubic meter) =	$19,400.00
	Abutment Cost	(2 standard abutments) x ($5,500.00 per abutment) =	$11,000.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	(2 cable anchorages) x ($6,000.00 per anchorage) =	$12,000.00
Total Cost	**M + C + P + S**	**$399,444.53 + $27,200.00 + $7,000.00 + $89,400.00 =**	**$523,044.53**

This feature allows the user to analyse the breakdown of costs associated with the bridge. Users can then decide what options are available to minimise the production cost.

Figure 7: Simple Truss Bridge Design



3.7 Bridge 21 Learning Model

Another key component to the design of the learning intervention in this study, is establishing a 21st century learning environment to deliver the learning experience. Voogt and Roblin's (2012) meta-analysis on current 21st century frameworks highlighted the important features that a 21st century learning environment must include. Inherent to these learning environments the ability to "communicate, collaborate, display creativity, critically analyse and develop social or cultural skills" (Voogt & Roblin, 2012, p. 309) were emphasised. Similarly the significance of attaining and developing these skills is well defined in the foundation of the new Junior Cycle Programme in Ireland, with a particular weight on developing problem solving skills (NCCA, 2014).

Designing learning environments that can accommodate 21st century learning principles and the incorporation of technology in learning experiences in the conventional classroom can be difficult. Bridge 21 is pedagogical model for 21st century teaching and learning that has proven to be successful in creating innovative learning experiences. The model has been shown to promote intrinsic student motivation and enhancing student engagement. (Tangney, Bray, & Oldham, 2015). Bray's Research (2015) presented the potential affordances on the use of technology to create contextualised and collaborative learning environments with the Bridge 21 model in maths education. The model has also been proven to be successful across various curriculums including, coding, languages and physics (Wickham, Girvan, & Tangney , 2016), (Bauer, Devitt, & Tangney , 2015)

A Bridge 21 learning activity is broken down into a number of steps: "Set Up, Warm Up, Investigate, Plan, Create, Present and Reflect" (Tangney , 2013, p. 47). The model allows students to collaborate and construct artefacts for the learning experience that can help give the teacher a clear representation of their understanding of the learning objectives. The role of the teacher in this learning environment is to scaffold the learning and assign deadlines that insure students are on task.

The Bridge 21 learning space should allow students to collaborate effectively in a technology mediated learning environment. Students are broken up into teams of three with one laptop per group. Each group has an individual working space for them to work collaboratively when problem solving. The learning space allows students to use technology in a conventional classroom setting.

Figure 8: Setup of Learning Experience.

3.8 Summary

This chapter has outlined the design of the learning experience used to attain data that will address the research questions proposed in this study. Five key components provide the foundations for the design of the learning activity. Each component was informed by the research discussed in the literature review. The design of an e-learning tool (website) to scaffold the learning activity and the use of a Microworld along with a SPSM were designed to develop student's metacognitive skills and problem solving skills. Problem solving is not taught in isolation. This study investigates the design of a 21st century learning experience with the use of a Microworld to develop these skills.

Chapter 4: Research Methodology

4.1 Introduction

To address the research questions proposed in this study a convergent mixed methods case study methodology was applied. This chapter will present the rationale for selecting a case study approach and discusses the data collection techniques chosen by the researcher for the acquisition of data to address the research questions. The context, background and setting in which the data collection methods are applied to elicit information to address the research questions are presented. The study investigates the effect of a SPSM on developing students metacognitive skills when delivered in a 21st century learning activity.

4.2 Research Questions

The research questions that are being addressed in this study are:

> *Q1. Does the use of the synthesized problem solving model (SPSM), enhance problem solving skills and metacognitive skills when problem solving.*

The following are sub questions that will be investigated in this research.

> *Q2. Sub Question: What role/impact did the Microworld simulation have in the process?*
>
> *Q3. Sub Question: What role did the Bridge 21 learning environment have in the process?*

Twenty one participants participated in the data collection to gain an insight into the impact of the learning intervention. The researcher acknowledges that the participant sample size is small and may be difficult to infer any statistical significance from the data gathered. To address this the researcher applied both qualitative and quantitative data collection instruments to gather data. As described in Section 4.7.1 a modified MCAI (Metacognitive Activities Inventory), instrument designed to measure student's metacognitive skilfulness during chemistry problem solving was adapted to gather quantitative data from the participants. Sample PISA Mathematics and Problem Solving tests (OECD & Assessments, 2009) were used to assess any changes in the participant's problem solving abilities. Qualitative data was collected through focus groups, field notes recorded by the researcher and observational analysis during the learning activities. To address the research questions a convergent analysis for common themes was conducted on all the data collected.

4.3 Ethics

Prior to implementation of the learning activity, the researcher received ethical approval from the University Ethics Committee. Permission was granted from the school's Principal and Board of Management, parents of the participants and the participants themselves to participate in the project. All parties received information regarding the nature of the research project and the researcher emphasised that all participants had the option -to withdraw from the research project at any stage. All information regarding ethical approval is attached in the appendices (8-10)

4.4 Researcher Bias

The participants involved in this study are students in the researcher's school. As a result, this may present a bias in the interpretation of the data and findings in the study. The researcher acknowledges that objectivity and personal input into the research may affect the data collected and understands that "Data may be filtered through the researcher's unique ways of seeing the world" (Rossman & Rallis, 2003, p. 38). To avoid any errors in the data collected the researcher ensured to minimise any possible influences on the participants that may conflict the data collected by highlighted that there are no "right" answers when asking for their opinion and ensuring that students can freely express their opinion. The researcher also incorporated independent observations into the data collection which is discussed in more detail in section 4.7.4.

4.5 Research Model

For the research methodology, a convergent parallel mixed method exploratory case study was selected. After reviewing, various research methodologies from the literature, an exploratory case study was selected as it satisfied the following criteria for the study: (Yin, 2014)(Cohen, Manion, & Morrison, 2007)(Ogawa & Malen, 1991)

- Can provide the reader with a rich description of the learning environment and interactions of participants in the learning activities in real life contexts.
- Allows for in depth analysis taking into consideration the small sample size.
- Allows for mixed data collection methods to be gathered from the participants in their natural setting.
- Allows for data collection of complex phenomena in real life contexts.

Cohen et al (2007) highlight the benefits of applying a case study approach when conducting research. A case study can provide an insight and “a sense of being there” by providing a rich description of the behaviour and interactions of the participants in their natural setting. It is important that the researcher gathers data that represents students in a traditional and conventional classroom setting so that data collected can provide an analysis on the impact of the learning intervention in the a traditional context. Similarly, Yin (2014) and Malen (1991) echo these sentiments on exploratory case studies, stating that case studies can provide a “detailed portrait and a coherent narrative depiction of complex phenomena” (Ogawa & Malen, 1991, p. 271).

The researcher acknowledges that some issues may arise in applying the case study approach as the research methodology. Some of the concerns include; (Yin, 2009)

- The exclusion of data,
- Researcher bias in analysing and interpreting data,
- Relying on the subjective judgment of the researcher.

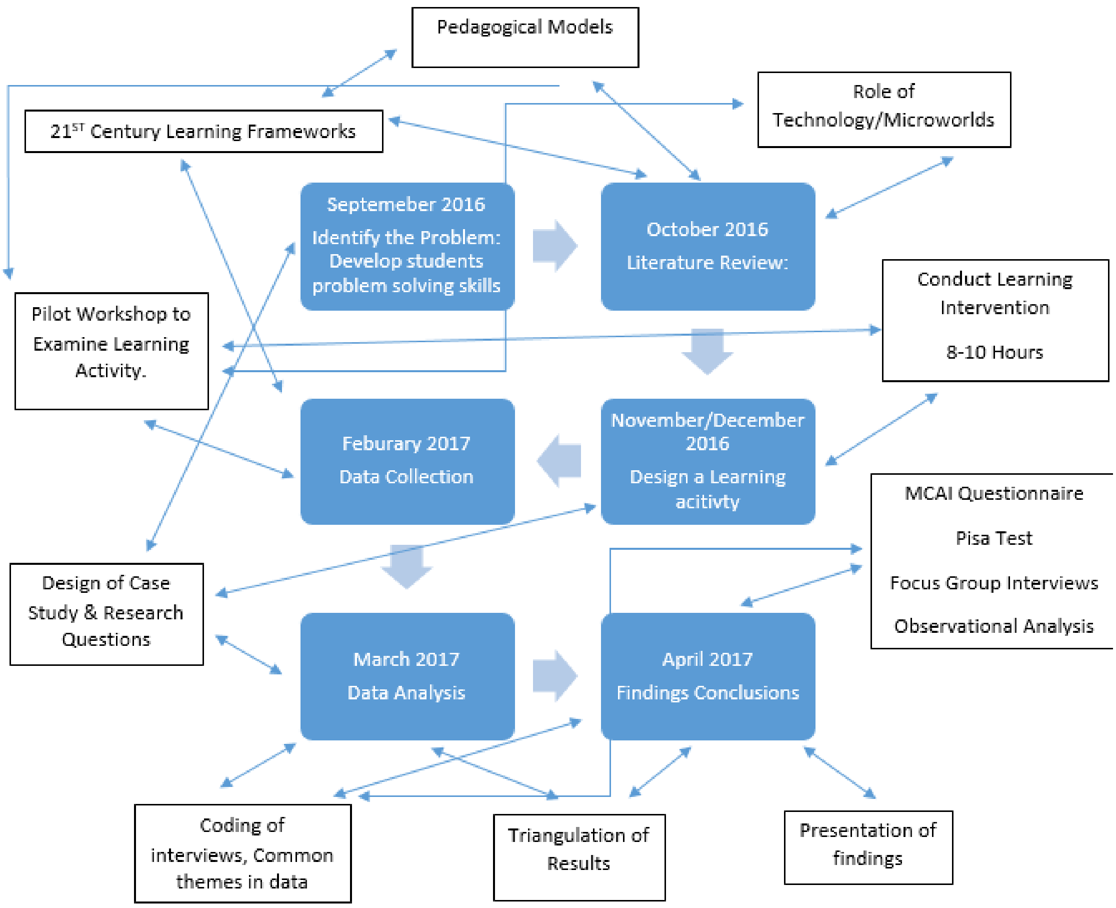
However to provide a validated analysis of the study, the researcher will use a broad range of data collection techniques. Usually case studies acquire data from multiple sources, including surveys, field notes, indirect or direct observation, informal or in-depth interviews (Ogawa & Malen, 1991). Creswell (2009) and (Cohen, et al, 2007) emphasise the importance of collecting detailed qualitative data such as interviews, field notes and observational analysis when applying a case study methodology. This study also collects data from observational analysis from Maths teachers observing the effect of the lessons. Essential to the data analysis is the triangulation of data to produce evidence to investigate the research questions proposed in the study.

4.5.1 Timeline of Research Investigation

This study commenced by exploring how student’s problem solving skills could be enhanced. A review of the literature highlighted the need for the design of synthesised set of heuristics for problem solving. Problem solving is not taught isolation so the design of a learning activity that could develop problem solving skills. Five key elements that underpin the design of the learning activity include the Pedagogical approach, Problem Solving Model, Role of Metacognition, the use of Technology and 21st Century learning framework. The collection of qualitative and quantitative data was collected to provide an in depth investigation on the impact of the learning intervention. Data was triangulated and analysed to address the reseach questions.

Figure 4.1 outlines the timeline for the research project and the key stages and themes that addressed the research questions proposed in the study.

Figure 9: Timeline of Study



4.6 Implementation

Three separate learning interventions were delivered to three sets of participants by the researcher. Firstly, an initial pilot investigation was conducted with 20 Transition year participants to evaluate the design of the learning activities. After amendments were made to the design, 21 different Transition year (15-16 year old) students participated in the learning activities.

This learning intervention was delivered over a 4-week period with a total of 8-10 hours in duration. Finally, a smaller and modified learning activity was deliver to younger group of 18 students (aged 12-13) for a 2 hour learning activity to assess their thoughts on the learning activity. Participants were selected as a convenience sample from the researcher's school. The learning activities were delivered in an after school STEM science club. Participants were familiar with the Bridge 21 learning model and are have experience with working in groups.

4.6.1 Pilot Learning Activity

The researcher conducted a pilot learning activity 3 weeks prior to the start of the main study. A similar cohort of 21 Transition Year Physics students were selected to test the design of the learning experience. The aim of the pilot learning experience was to investigate the following areas:

- Are the students able to understand/apply the steps to the problem solving model?
- Is the Microworld selected suitable for the learning experience:
  - Does it allow for high levels of problem solving?
  - Is the software student friendly?
- Are the open and closed problems solving questions suitable?
- Determine the suitable number of students for the task.
- Examine the range of scaffolding support the teacher will need to provide.
- Review the time required for various stages in the learning activity.
- Assess the website designed to support the learning activity.

The pilot workshop highlighted a number of recommendations that would benefit the design of the learning activity. The researcher discovered that students would need extra support to use the Microworld effectively. A tutorial video was created that outlined the functions and tools available to students when using the software. Amendments to the closed problem solving questions were also made by adding a brief paragraph on each question to provide a context to each question.

4.7 Data Collection

For the purpose of this investigation, a mixed methods approach was applied to gather data on the learning activity. Incorporating a range of data collection methods allowed for the triangulation of data, which insured that multiple perspectives where considered when presenting the findings and allowed for the generation of more reliable data (Denscombe , 2010). Qualitative data was collected in the form of focus groups interviews and observational field notes from the researcher and external teachers. In addition, Quantitative data was gathered from the MCAI questionnaire and PISA Maths Test delivered pre and post the learning intervention.

4.7.1 MCAI Metacognitive Questionnaire

To measure the students level of metacognitive skills in the study, the Metacognitive Activities Inventory (MCAI) (Cooper & Sandi-Urena, 2009) was compleated before and after the learning intervention. The questionnaire is designed to allow educators to assess student's metacognitive skills. The tool consist of 27 questions and uses a 5 point Likert scale ranging from 1 strongly disagree to 5 representing strongly agree for each question. The importance of developing student's metacognitive skills while problem solving was discussed in chapter 2. The MCAI tool is useful for specifically measuring students "planning, monitoring and evaluating of their learning"(Cooper & Sandi-urena, 2009, p. 240).

The MCAI tool has been shown to be a reliable and valid data collection tool. Cronbach's coefficient of reliability of $\alpha > 0.85$ indicates a high acceptance on reliability on the data collected. 21 participants completed the MCAI questionnaire before and after the learning activity. The data was entered into excel to be analysed and interpreted. The data entered was crosschecked to insure that there were no discrepancies in the data. The MCAI questionnaire is attached in the appendices (4). .

4.7.2 PISA Mathematical Tests

To elicit information on the participant's problem solving ability, the students completed a sample of questions from the PISA mathematics tests before and after the learning intervention. The mathematical competency test is designed to assess students ability to "reproduce, connect and reflect" on mathematical topics (OECD, 2016).

The questions require the students to engage in mathematical ideas and are designed such that students can engage in the problem without being good at mathematical computations. The aim of the competency test is to assess student's problem solving process when solving real life problems (OECD, 2014), (OECD, 2016)

A pre and post sample PISA mathematics test of equal degree of difficulty was distributed to the participants. Students performed the test in an exam context and were allocated 40 minutes to complete each test. The researcher contacted PISA Ireland and applied the PISA marking scheme to the correct the student tests. The results were entered into excel and analysed further for statistical significance. A sample of the pre and post questions are attached in the appendices (6).

4.7.3 Focus Group Interviews

Qualitative data was gathered in the form of focus group interviews. The questions chosen for the focus group interview were selected to collect information on the learning experience. Carey (1994) outlines the purpose of a focus group is to elicit information in a semi-structured group session that is moderated by a group leader in an informal setting. Yin (2014) discusses the benefits of using focus groups to accurately obtain an insight into the participant's opinions and explore the group consensus on the learning activity. The data collected from the focus group will allow the researcher to review student's attitudes and opinions on problem solving. Two sets of focus groups interview with 6-7 participants were conducted before and after the learning intervention each lasting 8-12 minutes. A total of 45 minutes recoding time was transcribed for analysis.

Yin (2014) and Cohen et al (2007) highlight the importance on the setting, the behaviour and attitude of the moderator and the interactions between the participants and moderator as crucial to the accuracy of the information revealed and discussed. The researcher insured that the interviews took place in a comfortable setting (School library) and encouraged the participants to express their opinions freely. Similarly, the semi-structured interview style was chosen to allow for flexibility and spontaneous responses between the interviewer and the interviewees (Kvale , 2006) .

Rossman and Rallis (2003) echo the importance of "reflexivity", the reciprocal reactions and behaviour of the researcher and the participants throughout the interview. The researcher allowed the students to students to express their opinion freely at all stages during the interview.

The interviews were recorded and transcribed to allow for analysis of the data. Each participant was assigned a code and unclear statements were omitted from the transcript. A sample of the interview transcript is attached in the appendices (7, 15).

4.7.4 Field Notes, Observations and Students Artefacts.

Information was also gathered on the participant's participation and behaviour in the learning activities through observation. The researcher recorded a series of field notes to provide first hand data on the interactions and behaviour of the students in the learning activity. Observational research allows the researcher to capture multiple opinions and understand the diverse perspectives of the participants (Mack, Woodsong, McQueen, Guest, & Namey, 2011). This data can provide insights into the context, relationships, and the verbal and non-verbal behavioural traits to provide a detailed description of the participants in the learning environment.

Similarly, to other data collection methods the role of the researcher as an observer is important. Hatch (2002) states that it is important that the observer is not too intrusive of the participants in the natural setting, otherwise the data collected will lose its credibility. Likewise Cohen et al (2007) echo similar concerns about researcher bias and researchers judgement on the collection of accurate representations. To avoid any bias in the data collected the researcher designed an observational checklist tool for external teachers to record the student behaviour.

To compare and contrast the data collected from the field notes an observational tool was designed by the researcher. The tool was created to record student's use of the problem-solving model, student's use of the technology and students level of collaboration and cooperation's in the learning activity. Each theme was graded using a five point marking system. One point was awarded to "no evidence" and 5 points awarded to "strong levels of evidence" for each group. Five separate mathematics teachers were asked to use the observational tool to record the student behaviour in the learning activity under category. Each teachers was asked to observe one lesson and independently grade each group on the level of evidence that he/she deemed that each group was exhibiting on each category. The researcher explained how to use the observational tool to each teacher and explained in detail by providing examples of evidence for each category. Only when the researcher was fully satisfied that teachers new how to use the tool the researcher asked the teachers to observe the lesson.

Data was collected in the form of field notes where the researcher recorded a written account of the interactions between students in the group work, the conversations, the physical and emotional gestures and other observations to portray the participants in the learning experience. After each learning activity, the field notes were transcribed and expanded into rich descriptions of the learning activity. The notes where then further analysed and coded to triangulate the data from multiple sources. An example of the field notes recorded are attached in the appendices (12).

In total five separate observations were conducted and the results were entered into excel to be analysed. A mean score for each observation was calculated. An example of the observational tool is attached in the appendices (5).

Finally the students work and portfolios where also analysed to triangulate common themes in the data. A sample of the student's portfolios is attached in the appendices (16).

Table 4: Summary Table of the Data Methods and Tools used in the Study

Data Collection Methods	Analysis	Aim/Goal of Data Collection
Quantitative **Pre and Post Questionnaire**	➢ MCAI Instrument delivered to participants (18) pre and post to measure students metacognitive skilfulness specifically their skills in - Planning, - Evaluation - Monitoring	➢ MCAI instrument is designed to specifically assess students' metacognitive skilfulness during problem solving. ➢ Explore if there is any impact on students metacognitive skills before and after the learning intervention.
Quantitative **Pre and Post Sample PISA Problem Solving Test**	➢ A pre and post sample PISA Mathematics test consisting of eight Questions with equal degrees of difficulty delivered to participants (18) before and after learning activity.	➢ To assess students current level of problem solving ability and to investigate if the learning intervention could affect the students PS skills and ability.
Qualitative **Pre and Post Focus Group Interviews**	➢ Four sets of focus groups interviews were conducted with 6-7 participants in each group before and after the learning activity.	➢ To Investigate student's awareness on steps/skills involved when problem solving and explore student's levels of metacognitive skilfulness while problem solving. ➢ To explore if the PS model impacted on students attitudes to PS

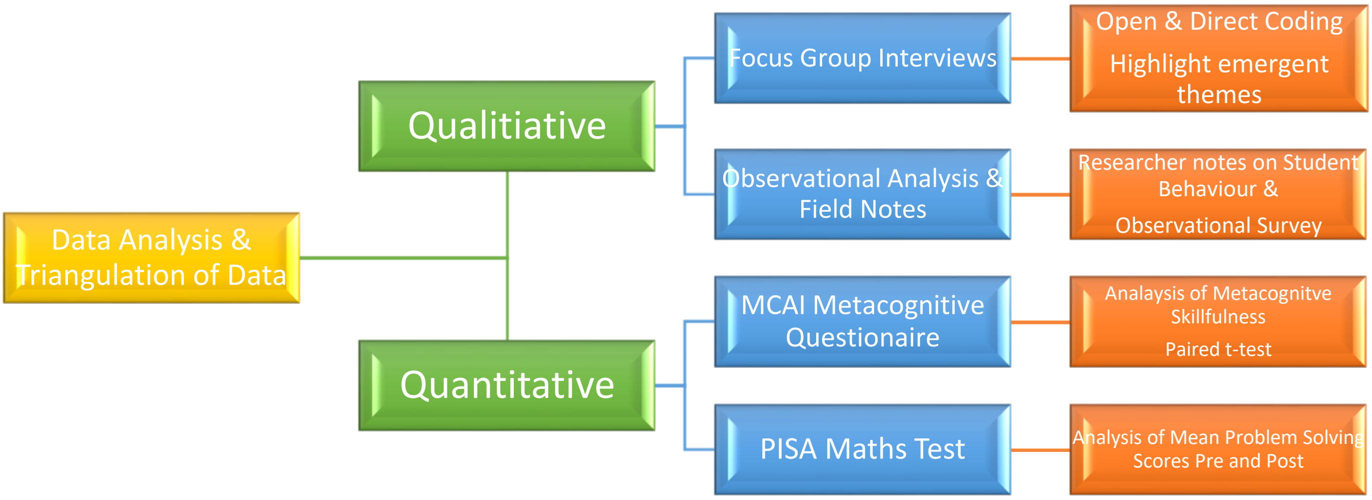
		➢ To investigate students attitudes towards the use of technology to help them problem solve. ➢ Explore Students attitudes to the learning activity on affecting their problem solving skills and ability.
Qualitative **Observational Analysis** **Reflective Field Notes by the Researcher.** **Student Portfolio/Work**	➢ Five observations where conducted by external teachers using an observational tool to record the student's behaviour in the learning environment. ➢ The researcher recorded observational field notes during the learning activity.	➢ To provide a rich description of the students activity/behaviour and involvement in the learning activity ➢ To record and analyse the students conversations and interactions in the learning activity to explore common themes and investigate if students level of metacognitive skills while problem solving.

4.8 Convergent Analysis

To provide an in-depth understanding and analysis of the data collected a convergent analysis of the data was carried out. A comprehensive account on the impact of this study can be obtained by the triangulation of the qualitative and quantitative methods used in this investigation. A statistical analysis was conducted on the MCAI data collected using a paired t-test procedures to determine any statistical significance.

Open and direct coding of the qualitative data from the field notes, focus group and observational analysis revealed a number of themes. Direct coding was used to measure student's use of metacognitive skills in the data. A final analysis of the qualitative and quantitative highlighted areas of congruency and key findings of the study. Figure 4.1 outlines the data analysis procedure used in the study.

Figure 10: Summary of Triangulation of Data Analysis



4.9 Summary

The chapter has presented the proposed research methodology used in this study. The decision to use a mixed methods exploratory case study to address the research questions outlined in this investigation is outlined. The collection of qualitative and quantitative data method and tools is discussed and method to provide a convergent analysis of the data is presented.

Chapter 5: Data Analysis and Findings

5.1 Introduction

This chapter will present the data collected to address the research questions proposed in this exploratory case study. A mixed methods approach was applied to gather data composed of qualitative and quantitative data. A convergent analysis of the data was conducted to highlight congruency within the data and the findings of the research questions are presented.

The main research questions that are being addressed in this study is:

> *Q1. Does the use of the synthesized problem solving model (SPSM), enhance problem solving skills and metacognitive skills when problem solving.*

The following are sub questions that will be investigated in this research.

> *Q2. Sub Question: What role/impact did the Microworld simulation have in the process?*
>
> *Q3. Sub Question: What role did the Bridge 21 learning environment have in the process?*

This chapter will present the data collected from the data tools used in this investigation. Firstly, the results from a pre and post questionnaire measuring students perceived metacognitive skills while problem solving is presented. Secondly, an analysis of student's performance in a pre and post PISA problem-solving test is discussed. Thirdly, a review of the observational analysis gathered is outlined, including the researcher's field notes and independent observations from other mathematical teachers. Fourthly, the transcripts from two sets of pre and post focus group interviews with the participants discussing their thoughts and feelings on the learning experience are analysed and coded for congruency, and finally a review of student artefacts created in the project are evaluated to assess student's performance in the learning activity. Due to the small sample size of n=21 and the short time of the learning intervention the researcher acknowledges there are limitations to the findings in this research investigation and these will be presented.

5.2 Data Analysis: Quantitative Data

5.2.1 MCAI Questionnaire

The modified MCAI questionnaire was distributed to participants before and after the learning experience. The results were entered into Microsoft Excel for further analysis. Due to the small sample size, a paired t test was used to identify any differences between the mean scores of the pre and post data for the participants. The test works on the principle of the null hypothesis, which states that if there is a difference between the sample means the result is significant. Data was analysed at the 95% confidence interval, which includes a two-tailed test when interpreting the data. This confidence will provide suitable statistical analysis for this study. Using the Likert scale of 1-5 for each question, the responses from each participant were entered into excel.

The MCAI Questionnaire measures the student's levels of metacognitive skills including planning, monitoring, reflecting and general problem solving skills while problem solving. The questionnaire analysed the total mean scores of the participants and each category was further analysed to highlight and significant differences. The data presented in table 5 & 6 below shows the mean scores of the participants and the analysis of the paired t-test results. The two-tailed T-Test shows a significant result with as the p-value is less than 0.05, which indicates a significant difference.

Table 5: Statistical Analysis for MCAI Questionnaire

T-Test: Paired Two Sample for Means		
	Post Test	*Pre Test*
Mean	66.5	58.9
Variance	83.8	66.2
Observations	21	21
Pearson Correlation	0.707	
Hypothesized Mean Difference	0	
df	20	
t Stat	5.22	
P(T<=t) one-tail	2.05186E-05	
t Critical one-tail	1.72	
P(T<=t) two-tail	4.10371E-05	
t Critical two-tail	2.085	

Table 6: Confidence Intervals for MCAI Questionnaire

Mean Difference	**7.61**
Standard deviation of Difference	6.68
Standard Error of Difference	1.45
T Alpha half 95% Confidence Interval	2.08
Lower Confidence Level	4.57
Upper Confidence Level	10.66

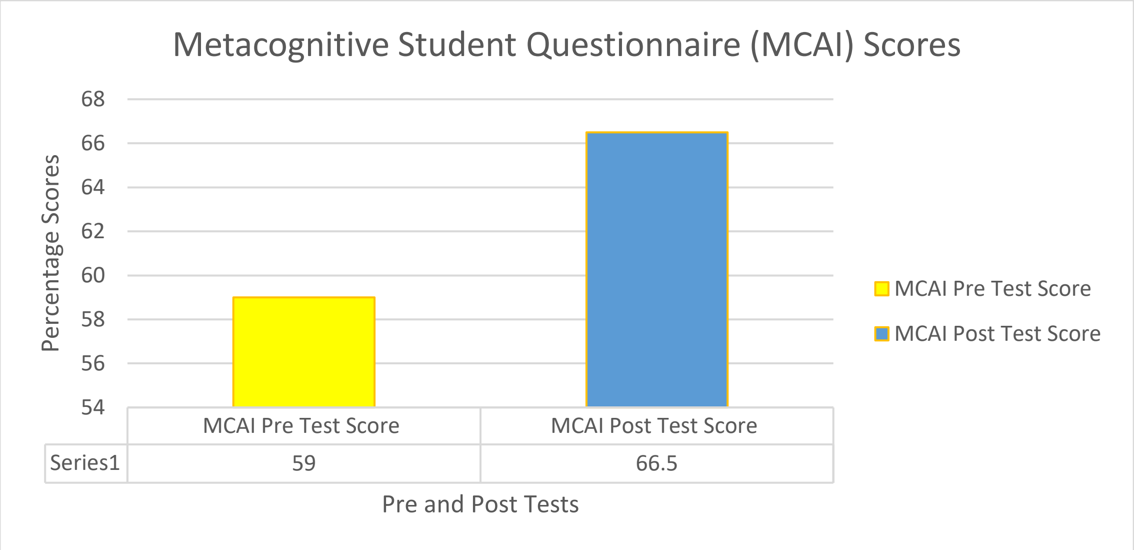
The data was collected by analysing the difference in the means of the samples (x), the standard deviation of the samples (s) and the size of the sample (n) using the formula:

$$t = \frac{x}{\frac{s}{\sqrt{n}}}$$

A two-tailed t-test at the 95% confidence interval was conducted and determined that a value greater than 2.086 is significant for the data collected in this study. A t value of 5.23 indicates that the difference in the mean scores is significant.

A further analysis of the MCAI data was conducted to compare any significant differences in the participant's scores before and after learning activity. The graph 5.1 below displays the mean scores for the participants.

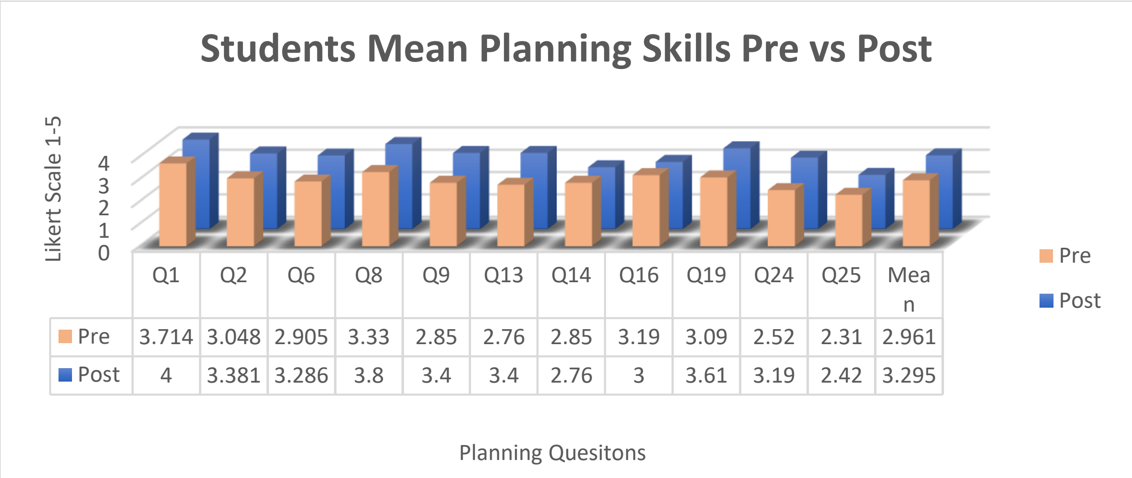
Graph 1: Student Metacognitive Scores Pre vs Post



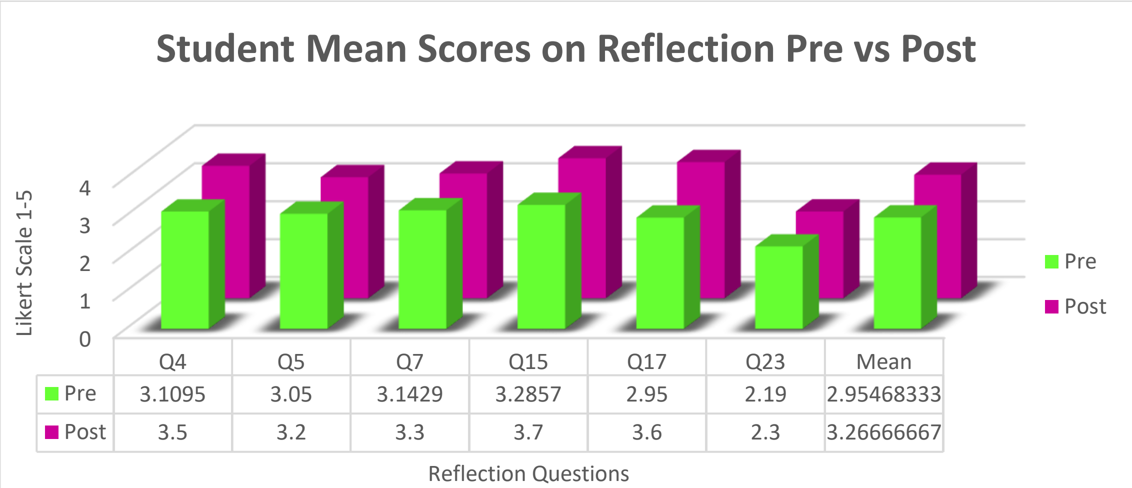
An analysis of the data indicates that there was an overall increase of 7.5 in the mean scores with 18/21 of the participants increasing their perceived metacognitive scores.

The MCAI questionnaire was further analysed under the questions type. Three categories of metacognitive skills (planning, reflection and monitoring skills) and one general problem solving skills category. The data was analysed and a series of graphs were created to display the results. The graphs highlight the how the overall increase of in the metacognitive skills is significant with an increase in the mean scores for each category

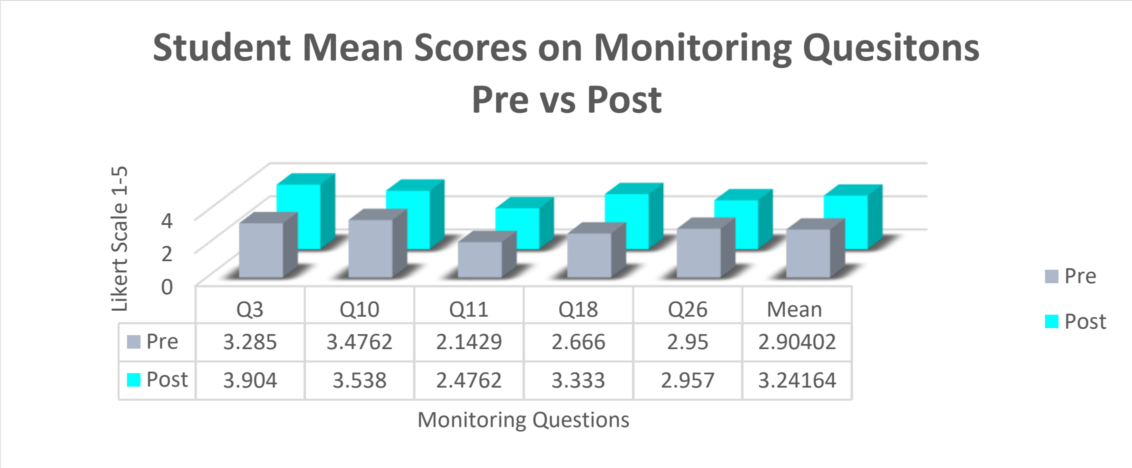
Graph 2: Student Mean Planning Skills



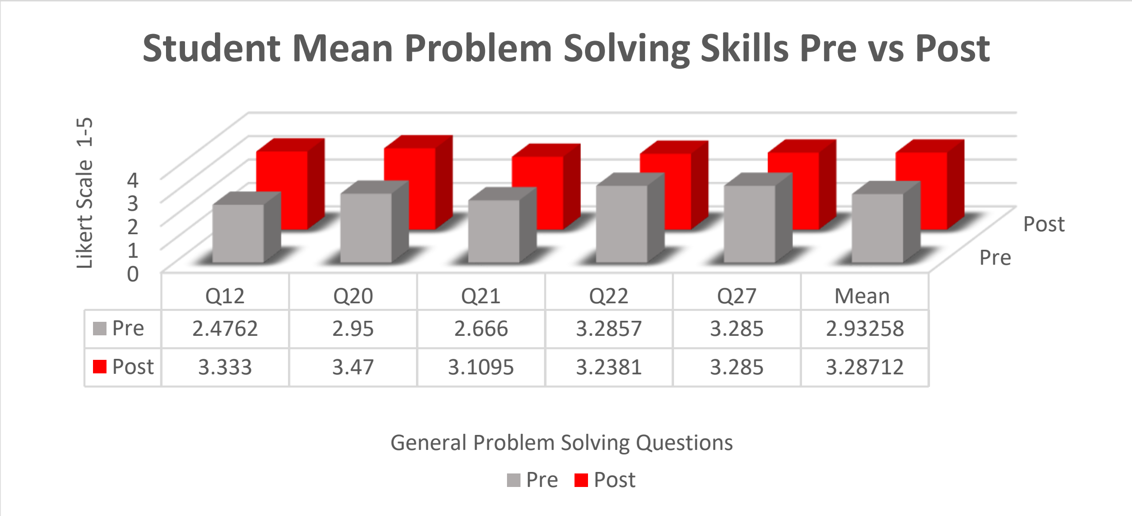
Graph 3: Student Mean Reflection Scores



Graph 4: Student Mean Monitoring Scores



Graph 5: Student Mean Problem Solving Skills



5.2.2. PISA Problem Solving Test

A series of data was collected and analysed to compare the participant's level of problem solving ability before and after the learning intervention. The results was entered into excel and analysed for congruency. Similar to the MCAI questionnaire a paired t-test was conducted to determine any significance in the mean scores in the pre and post-tests. Eight questions were completed before and after and the results were marked using the standardised PISA marking scheme. The data presented in table 7 & 8 below shows the mean scores of the participants and the analysis of the paired t-test results. The two-tailed T-Test shows a significant result with as the p-value is less than 0.05, which indicates a significant difference.

Table 7 Paired T-Test for PISA Tests

Paired T-Test for Two Sample for Means.		
	Post Test	*Pre Test*
Mean	41.94	38.47
Variance	299.05	303.81
Observations	19	19
Pearson Correlation	0.87	
Hypothesized Mean Difference	0	
df	18	
t Stat	1.77	
P(T<=t) one-tail	0.046	
t Critical one-tail	1.73	
P(T<=t) two-tail	0.092	
t Critical two-tail	2.100	

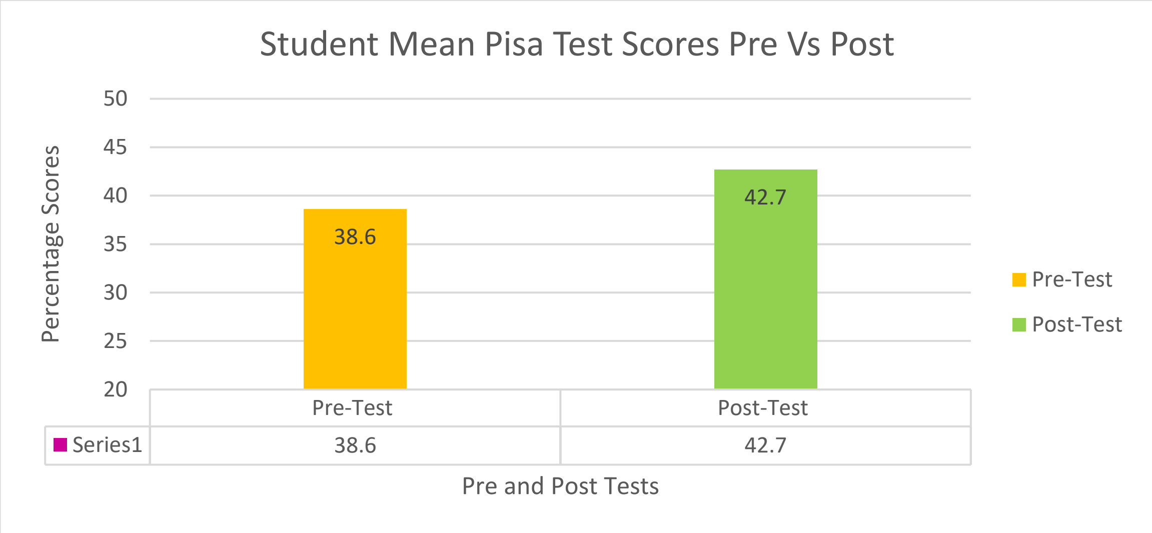
Table 8: Confidence Intervals for PISA Tests

Mean Difference	**3.278**
Standard deviation of Difference	8.43
Standard Error of Difference	1.93
T Alpha half 95% Confidence Interval	2.10
Lower Confidence Level	-0.786
Upper Confidence Level	7.34

A two-tailed t-test at the 95% confidence interval was conducted and determined that at value greater that 2.1009 is significant for the data collected in this study. A t value of 1.775 indicates that the difference in the mean scores is not significant.

A further analysis of the PISA scores was conducted to compare any significant differences in the participant’s scores before and after learning activity. The graph 6 below displays the mean scores for the participants.

Graph 6: Student Mean Pisa Test Scores



An analysis of the data indicates that there was an overall increase of 4.1 in the mean scores with 14/21 of the participants scoring higher in the post problem-solving test.

5.2.3 Observational Analysis

Two types of data were collected in the form of observational analysis in this case study. The first series of data was collected in the form of field notes that the researcher recorded throughout the research investigation. Observational data was also gathered in the form of an observational recording tool designed by the researcher. The tool was designed to record the levels of evidence for three different categories; Use of the Synthesised Problem Solving Model, Effective use of Technology and levels of Participation & Engagement in each group. Five observations were conducted by five different Mathematics teachers to record the behaviour and participation of the students in the learning activities. Table 5.1 below shows how the data was analysed in the case of the effective use of the SPSM. A mean score was calculated to represent the mean group score for the class for each learning activity.

Table 9: Observational Data on each Group for the use of the SPS Model in Different Observations

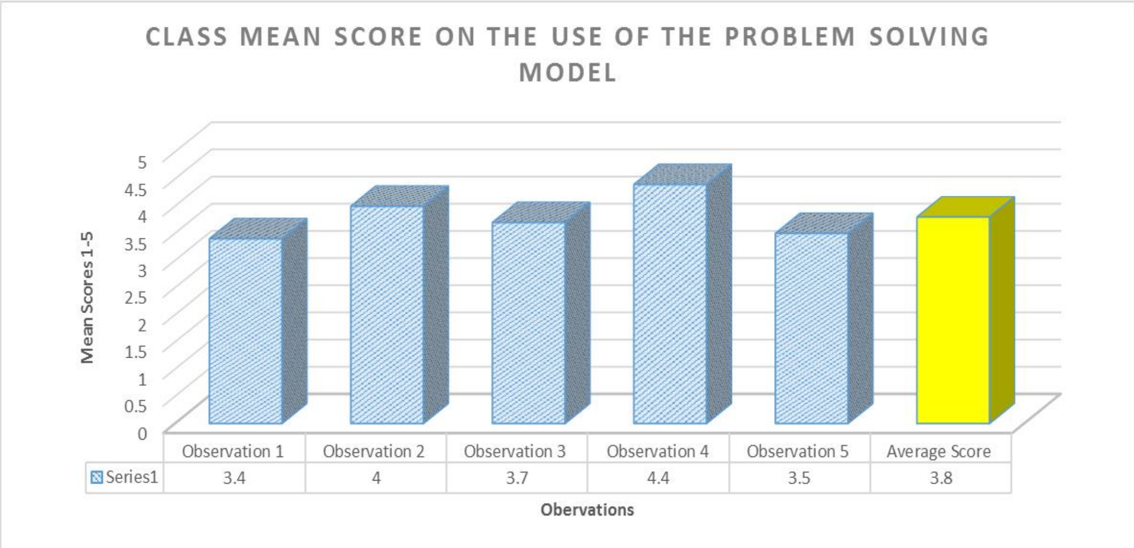
	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5	Average Score
Group 1	4	4	5	5	4	4.4
Group 2	3	4	5	5	4	4.2
Group 3	4	4	4	5	3	4
Group 4	3	3	2	3	2	2.6
Group 5	4	5	4	5	5	4.6
Group 6	2	4	2	3	3	2.8
Mean Score	3.33	4	3.67	4.33	3.5	3.76

Table 10: Table of Data for Observations vs Class Mean Score

Observations	Mean Score
Observation 1	3.4
Observation 2	4
Observation 3	3.7
Observation 4	4.4
Observation 5	3.5
Average Score	3.8

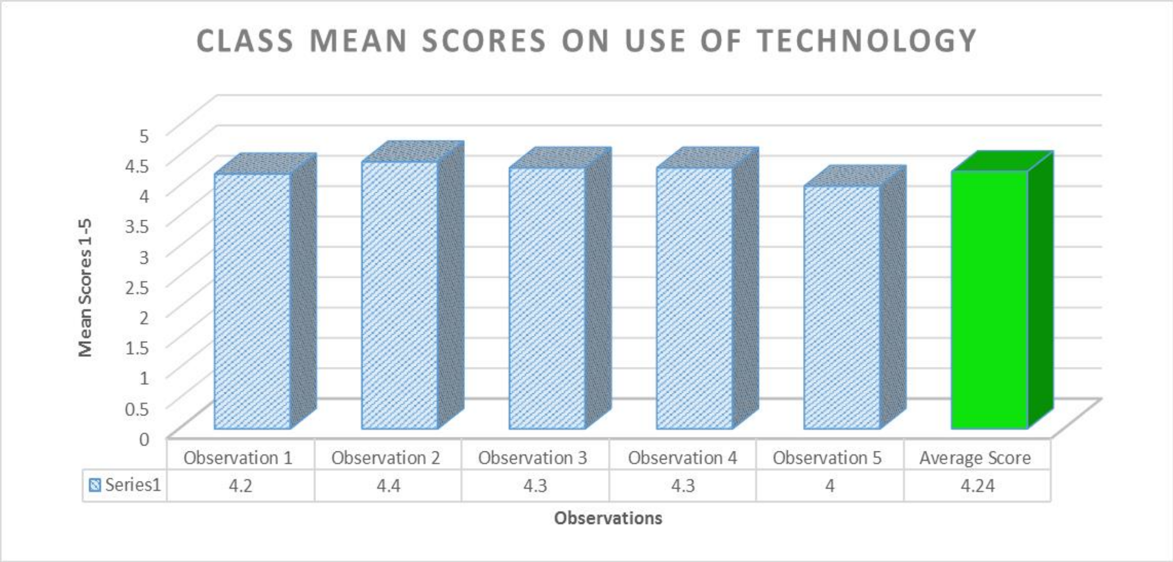
Similar sets of data analysis was conducted for the effective use of technology and participation and engagement levels in the learning activity. There sets of graphs were created to display the observational analysis recorded in the study.

Graph 7: Observational Analysis on Class Mean Scores on Use of SPS Model



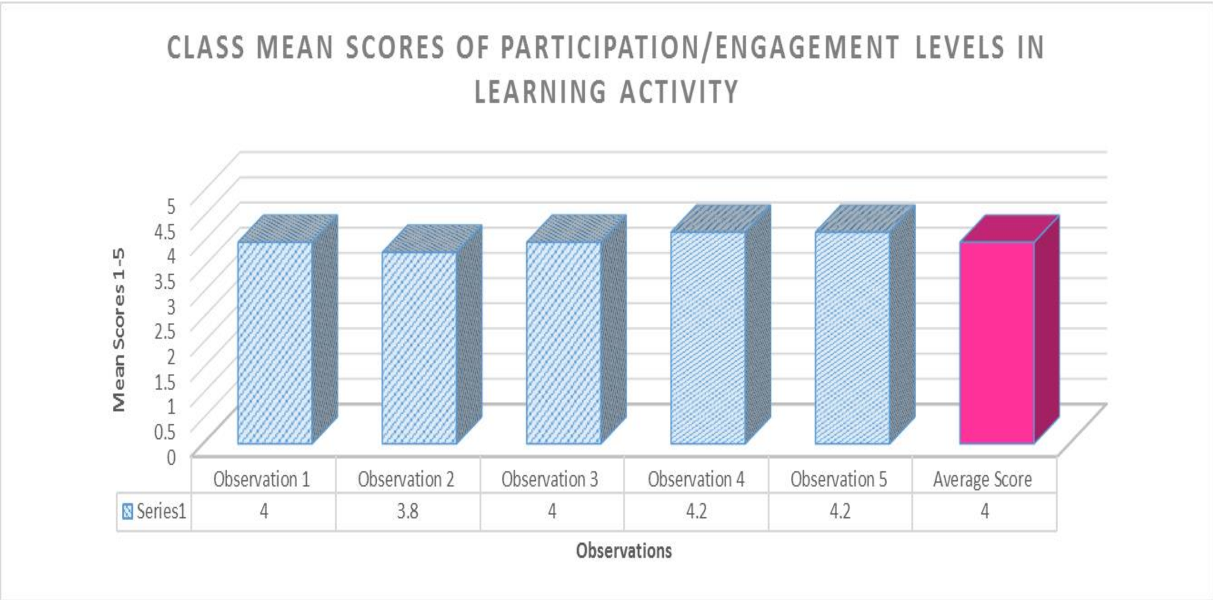
The graph highlights that teachers graded a mean score of 3.8/5 on the effective use of the SPS model in learning activity.

Graph 8: Observational Analysis on the Class Mean Scores of use of Technology



The graph highlights that teachers graded a mean score of 4.24/5 on the effective use of Technology in learning activity.

Graph 9: Observational Analysis of Class Mean Scores of Participation and Engagement Levels



The graph highlights that teachers graded a mean score of 4/5 on the positive levels of Student Participation and Engagement levels in the learning activity.

5.3. Data Analysis: Qualitative Data

5.3.1 Focus Group Interviews

To provide a rich description and deeper insight into the impact on the design of the learning activities from the perspectives of the participants a set of focus group interviews were conducted. This allowed the data to be analysed from different perspectives allowing for a greater depth of the analysis of the data. Two sets of pre & post interviews were conducted before and after lasting 45 minutes in total. Two groups of seven students, consisting of three females and four males were selected to participate in each focus group before and after.

A semi-structured interview was conducted to elicit information on five specific categories chosen by the researcher collect data the design and role of the learning experience when problem solving. These include 1) Students attitudes to Problem Solving, 2) thoughts on the use of the SPS model, 3) students feelings on the use of technology in the learning activity, 4) the Bridge 21 learning model and 5) students thoughts on their learning experience in the project.

The interview was transcribed directly after each interview and the researcher recorded notes on student's behaviour and attitude in each session. A series of themes outlined in table 7 were directly coded, and any emerging themes were openly coded. The researcher hand coded the data, as it was felt that this would provide the researcher with a greater understanding and appreciation of the data. An example of the interview transcript and the coding analysis is attached in the appendices.

5.3.2 Observational Analysis: Field Notes

Throughout the learning activity, the researcher recorded a series of field notes on the behaviour, attitudes and a description of the interactions between the participants. This allowed the researcher to represent the data from another perspective and allowed the researcher provide a detailed and comprehensive analysis on the impact of the learning activity on the participants.

At the end of each learning activity, the researcher transcribed the data into Microsoft Word so that it could be be further analysed. The transcripts were then coded for similar themes present in the data. A sample of the transcribed field notes is attached in the appendices.

5.3.3. Student Artefacts

Students were asked to produce a portfolio of the work that they produced in each of the learning activities. Each group submitted a portfolio online outlining their solution and design they created to answer the closed and open-ended questions investigated in this investigation. Students were asked to provide a detailed commentary on the rationale for how the approached the problem, how they answered the problem and a reflection on their solution. The researcher analysed the student artefacts to highlight any common themes that emerged from the data. An example of a student portfolio is attached in the appendices.

5.3.4 Directed Coding: Themes & Analysis

The data collected from the transcripts, field notes and student artefacts were coded to allow the researcher to compare common themes in the MCAI questionnaire, PISA tests and observational analysis conducted in this study. The aim of the coding was to highlight positive and negative perceptions about the SPS model, the use of technology in the learning activity and the role of the Bridge 21 learning model. Reviewing the transcripts and attitudes of the participants in the pre focus group interview, it was immediately clear that a common themes such as; strategies applied to problem solving and general attitudes towards problem solving were present in the data. Table 3 provides a detailed description of the codes assigned to the each theme that were directly coded in the pre and post interview transcripts. Each theme was manually coded and the frequency totals were calculated. The researcher re-coded the transcripts again to insure accuracy in the data collected. An example of the how the researcher coded the focus group data and field notes is outlined below:

> "You start to learn by looking back at your mistakes and then you can change your design or fix the bridge, you can check to see what worked and what didn't"

This statement was coded with **A2** (positive use of the SPS model) & **C3** (positive use of the technology to help with learning).

Similarly, data from the student artefacts was coded as shown below:

"This was a fun problem, we discovered that the bars were two weak for the bridge to function, so we replaced the hallow tubes with solid bars so they would be more efficient, and then we tested our design to see what bars we could reduce the size of to be more cost effective"

This was coded with **A2** (positive use of SPS model), **C3** (positive use of technology to help with learning), **B3** (positive attitude to problem solving) .

Five categories/themes were directly coded to provide a rich description on the effect / design of the learning activities and to analyse the perceptions and attitudes of the participants.

Table 11: Categories & Themes that were Directly Coded

Category	Code	Source of Data	Themes
Evidence of Use/Awareness of Problem Solving Strategies	Pre Any Evidence: **A1** No Evidence: **X1** Post Any Evidence :**A2** No Evidence: **X2**	Coding of Focus group transcripts Coding of Observational analysis MCAI Questionnaire Student Artefacts	Metacognitive Skills -Planning -Monitoring -Reflecting (checking answer) Strategies: reading, understanding, trial and error Creativity / Innovation Higher order thinking Questioning
Thoughts on the Synthesised Problem Solving Model	Post: Positive: **A3** Negative: **A4**	Coding of Focus group transcripts Coding of Observational analysis MCAI Questionnaire	Metacognitive Skills -Planning -Monitoring -Reflecting Help/Support Structure Easier to PS Understanding Decisions/Ideas

Attitudes to Problem Solving	Pre Positive: **B1** Negative: **B2** Post Positive: **B3** Negative: **B4**	Coding of Focus group transcripts Coding of Observational analysis MCAI Questionnaire	Positive Experience Fun Question type Easy Critical Thinking / Analysis Negative Experience Frustrating Hard Got Better
Effect of Technology when Learning	Pre: Positive: **C1** Negative:**C2** Post Positive: **C3** Negative: **C4**	Coding of Focus group transcripts Coding of Observational analysis Student Artefacts	Fun Visual Easier to learn Constructionism Engagement Imagination Creativity Help/Support Motivate
Effect of the Bridge 21 Learning model	Pre Positive: **D1** Negative: **D2** Post Positive: **D3** Negative: **D4**	Coding of Focus group transcripts Coding of Observational analysis Student Artefacts	Discovery based learning Group work, Structure Scaffolding, Fun / Enjoyment Engagement / Work Rate Responsibility.

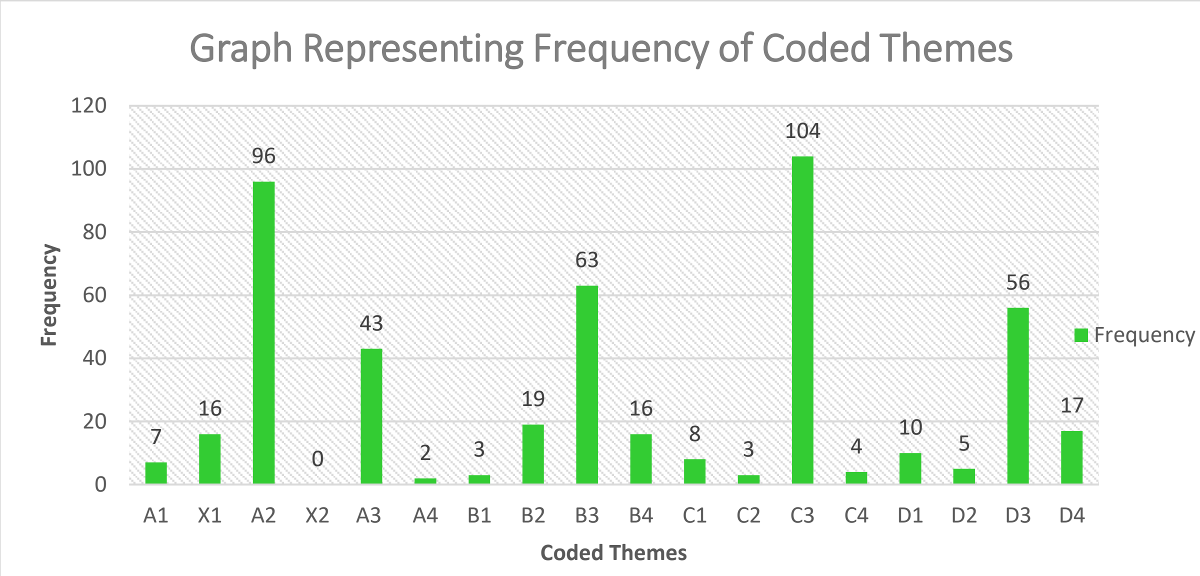
The transcripts of the codes were further analysed and the frequency of the codes were calculated and entered into Microsoft Excel for further analysis. Table 12 reveals the frequency for each code from the data collected.

Table 12: Frequency of Codes in Data

Category/Theme	Code	Frequency Total	Pre - Focus Group Coding	Post - Focus Group Coding	Field Notes Coding	Student Artefacts
Evidence of Use/Awareness of Problem Solving Strategies	A1	7	7	0	0	0
	X1	16	16	0	0	0
	A2	96	0	23	26	57
	X2	0	0	0	0	0
Thoughts on the Synthesised Problem Solving Model	A3	43	0	31	12	
	A4	2	0	2	0	0
Attitudes to Problem Solving	B1	3	3	0	0	0
	B2	19	19	0	0	0
	B3	63	0	29	14	20
	B4	16	0	9	3	4
Effect of Technology when Learning	C1	8	8	0	0	0
	C2	3	3	0	0	0
	C3	104	0	36	10	58
	C4	4	0	1	3	0
Effect of the Bridge 21 Learning model	D1	10	10	0	0	0
	D2	5	5	0	0	0
	D3	56	0	25	17	14
	D4	17	0	9	4	4

The frequency of the coded data is graphically represented in graph 10 below. The graph highlights a number of frequent themes that appear to be significant in the data collected. Firstly, code A2: n=96, highlights significant evidence to support the use/awareness of problem solving strategies in the learning activity. Secondly, code A3: n=43 draws attention to the positive use of the SPS model in the learning activity. Thirdly code B3: n=63 highlights post attitudes to problem solving in the learning activity. Fourthly, code C3; n=104 appears to indicate positive/effective use of technology to support students when problem solving. Finally, code D3: n=56, reveals that participants appear to have a positive learning experience with the Bridge 21 learning model.

Graph 10: Frequency of Coded Data



5.4 Findings

This section will present the main findings of the research project and triangulate the data to address the research questions proposed in this study. Data is selected from both sets of qualitative and quantitative to highlight and provide congruency on the findings.

5.4.1 Evidence to Address Research Question 1

To address the first research question proposed the researcher will provide a range a evidence to answer the question.

1. Does the use of the synthesized problem solving model SPSM, enhance problem solving skills and metacognitive skills when problem solving.

Firstly, the importance of developing effective metacognitive skills when problem solving has been highlighted in the literature (Veenman et al,2006). In developing the student's procedural knowledge this can create more efficient problem solvers.

Reviewing the data collected, an analysis of on the awareness on problem solving strategies and metacognitive strategies when problem solving indicates that this set of participants had a low level of awareness initially with scores of A1=7 compared to X1=16. This result is echoed with students revealing their methods to problem solving;

> "*There is no real strategy, just looking at it and reading over the question"*
> *"Like we have never been thought how to problem solve so we just try it and guess"*

In contrast some students did have some techniques but were lacking in detail and in structure,

> "*Yeah I suppose I try and find the important bits, like looking for the parts you need to answer and just keeping looking at the problem and trying to understand it"*

So initially, the data appears to indicate that students overall awareness to problem solving strategies could be developed. In comparing the data to students use of the SPSM to help them problem solve, the data appears to indicate the positive and effective use of the model to help students when problem solving. Firstly, the frequency on the effective use of the model, code A2= 96 indicates that students demonstrated effective use in the model. In Addition, code X2= 0 highlighted that there was no cases in the learning activity where students did not use some metacognitive skills or problem solving skills in the learning activity. An example of the conversations that student's where having in the learning activities to address the problems is presented below:

> "*How do we make this member less wobbly, and we need to get these members to be more blue and red in colour to maximise tension and compression forces"*

> "*We need to fix all the top bars, because I think that's where it is under the most stress, we can check the load test to see which members are under pressure"*

It can be seen from the above examples that students where actively developing their metacognitive skills in the learning activity. Similarly, reviewing the data on the use of students thoughts of using the SPS model, the data appears to reinforce the argument that the model can be used to enhance students metacognitive skills when problem solving. The frequency of A3=43 highlights the positive attitudes towards using the model the learning activity. Students reaffirmed this in the focus group interview outlining how the model assisted them while problem solving.

"Like the steps helped us on how to problem solve, and gave you hints, for like what to do next and how you have to do it"
"Your brain does be all over the place when you get confused so looking at the model kind of slows your thought process down and breaks the problem into little steps"

The researcher recorded an important observation on the participant's problem solving strategies in the initial learning activities. Reviewing the field notes, he highlighted that,

> "*Some of the students because of their, knowledge, experiences and attitudes seem to jump straight into the problem and do not use the initial steps to break down the variables in the problem. As a result some students then get easily frustrated when there solution does not work"*

Evidence to support this claim is apparent in the response's from the focus group interviews,

> *"Yeah like I thought the problem was a good way to practice your problem solving skills, like I usually don't stop and think how am I going to do the problem, but when using the problem solving model was really good, for kind of directing and helping you to break down the problem. Like until you told us to slow down and use the model myself and x where just guessing about how to do it… not really working out a plan or checking it"*

Another interesting piece of data that was appears to be evident is the students use of reflection when problem solving. In the pre interviews, some students acknowledged that they rarely checked their answers and moved straight onto the next question when problem solving. In contrast, in the post interview and the observational field notes, evidence to show that students are reflecting and rationalising the decisions they make is evident. From the field notes, the researcher recorded the following observation;

> *"Students are showing good thought processes. Their levels of higher order thinking is high with students questioning and challenging each other and reflecting as a group on the best idea to choose…….students are showing a high level of maths and physics knowledge when they are analysing the load tests".*

An important observation that the researcher noted about the particular participants in the learning activity was that the participants have been practising maths for over 10 years and as a result, the effect of their attitudes, beliefs, knowledge and past experiences had an effect on the student's proficiency in problem solving. Students outlined that this would have been helpful if the students had been thought this problem-solving model at an early age.

"*Like sir, at the end of each chapter there is problem solving questions but we learned a model like this on how to problem solve, like I think this would have been better if we learned this in first year and it would have helped us instead of getting annoyed with maths".*

Nonetheless, evidence to support the effective use of the problem-solving model appears to be evident from the observational analysis conducted. The mean class score for the effective use of the SPSMI scored 3.8/5, which appears to indicate good levels of evidence that on average the participants utilised the problem-solving model to assist in their learning.

There is also evidence in the field notes and student artefacts with students demonstrating the use of metacognitive skills in their portfolios.

"We firstly looked at the problem and worked out what had to be fixed, we then reviewed the bridge design and discovered its faults, the supports underneath were not efficient and it would not support its own weight and the weight of bridge and truck……………..So we decided to change the member material, design and size and check to see how that effected overall structure"

Analysing the results of the student's level of problem solving skills before and after showed no statically significant increase in the mean scores. However, due to the short time frame of the learning experience it was not envisaged that these results would be significantly different. The researcher acknowledges that there are a number of factors and variables to be considered when developing ones problem solving skills other than metacognitive skills.

In contrast to the results from the PISA tests, an analysis of the mean scores for the metacognitive questionnaire showed a statically significant increase in the post mean scores after the learning activity. This result appears to indicate that the participant's perceived use of metacognitive skills had increased after the learning intervention.

Notwithstanding the small sample size and the short time frame of the intervention, the data appears to indicate the SPSM had an effective impact on developing students metacognitive skills when problem solving. Further researcher would need to be conducted to develop a more coherent and detailed synopsis on the impact of the SPSM on other aspects of the student's problem solving skills.

5.4.2. Evidence to Address Research Question 2

To address the second research question proposed the researcher will present synopsis of the evidence to answer the question.

Q2. Sub Question: What role/impact did the Microworld simulation have in the process?

The use of technology that lies in the redefinition and transformation categories of the SAMR model and the literature discussed in this study have highlighted the potential for the use of technology to enhance learning environments (Puentedura, 2006). The researcher will present evidence that allowed the students to develop their metacognitive and problem-solving skills through the use of the Microworlds selected.

Firstly, analyzing the frequency of the themes in the qualitative data reveals the code C3: n=104 had the highest coded frequency after the data was analysed. This result appears to indicate the positive use of technology to create an enjoyable learning experience where students enjoyed practicing their problem solving skills through interacting with the Microworld.

> *"Yeah I much preferred doing problem solving by using the technology, rather doing problem solving from a book"*
> *"Yeah I liked answering the problems using the software, it was almost like a game, its easy to learn in games and you want to try and get to the next level"*

Similarly, students outlined the positive attributes of the technology that helped them to problem solve. These factors included the ability to create, design, visualise and test your solutions and interact with your ideas when problem solving.

> *"Yeah like I think the project was good at making us be creative and critically think about the design and structure of our bridges, sometimes in Maths we don't get to be creative and innovative in Maths and it's hard to reflect on our answers because we cannot check to see if they are right or wrong"*

In addition to that perspective above, students also outlined how the technology allowed them to test and reflect on their design and critically analyse their ideas. In essence, the interacting allowed the students to demonstrate their higher order thinking skills and practice and develop their reflective skills by analyzing the data in the Microworld.

“An annoying thing when you do problem solving on paper is that it’s hard to see if you are going right or wrong, you don’t get much feedback and it’s hard to visualise what’s going on. Like I thought the simulation was good because you could look at your design and see the red and blue lines that indicate the level of pressure being exerted on the bridge at them points”

“Yeah it was cool that you could learn from your mistakes and change your design, it kind of helped you and you could work out by analysing the load test and and testing your bridge”.

Furthermore, the role of the Microworld to allow the students construct their own designs allowed the students to engage more in the learning experience and also allowed the students create meaning from their own learning experience. Comparing the steps in the SPSM with the Microworld, the software allowed the students to plan, monitor and reflect on while problem solving by allowing the students to interact and engage with the problems by using the software.

“*Yeah it’s easier to learn, like you don’t even realise that you are doing maths, but you actually are and you can see the maths seems easier when using the technology”*

In addition to the evidence produced from the focus groups, data from the observational analysis highlighted that the mean class score for the effective use of technology as measured by the teachers was 4.24/5 which demonstrates that the students were using the software effectively when problem solving. Reviewing the student artefacts that they produced revealed high levels of critical thinking, metacognitive skills and interesting and diverse solutions to various problems.

“Yes, it worked, and we got our design to be under €450,000, I feel so proud of myself, are you happy sir…..this is so cool, why don’t we make a bridge that has our initials as the main supports in the bridge”

It is however important to acknowledge alternate opinions of the use of the technology. Many students highlighted that they enjoyed working with the software and laptops in the learning activity because it was “novel” and “something different” which raises the question after time would the students be as interested in learning and developing their problem solving skills with the use of technology.

Furthermore, evidence that indicates the negative effects of technology in the learning environment was present with codes B4: n= 16 and C4: n= 4 revealing some negative attitudes towards problem solving. Students outlined that they got annoyed and frustrated with the technology if their design would not work initially.

> *"Some groups got a little frustrated because their designs were too complicated and the structural safety of the bridge was too difficult to design"*

An alternate attitude from some of the participants on the use of technology was discussed in the focus groups. This is something that educators must consider the rationale for introducing technology in the classroom.

> *"I don't think it is good bringing technology into maths, because it makes it too complicated and you're just exposing us to more internet and laptops when we already spend so much time on them at home, like school is a break from technology for us"*

Similar to limitations outlined for answering research question one , the data appears to indicate the use of a Microworld had an effective impact on developing students metacognitive skills when problem solving. The affordance of the Microworld to help students develop these skills though interacting and engaging in the learning experience appears to have a positive impact on the participants.

5.4.3. Evidence to Address Research Question 3

To address the final research question proposed the researcher will discuss a range of evidence and data to answer the question.

> Q3. Sub Question: What role did the Bridge 21 learning environment have on the process?

Chapter 3 in this study discussed the importance features that were considered when designing the learning intervention for this research investigation. One important feature was the use of the Bridge 21 learning environment to scaffold the learning experience that was student centred and allowed for the incorporation of a technology mediated learning experience.

Firstly, reviewing the data from the focus group interviews highlights that the majority of students had a positive attitude and evidence on the design of the learning and the use of the Bridge 21 learning model. Code D3: N=16 demonstrates the high frequency of evidence to support the use of the Bridge 21 learning model.

> *"Yeah it was fun I enjoyed the learning experience, you gave us a lot more control and we could make our own decisions, and you kind of let you work out the problems for ourselves which was good because we learned more by doing it ourselves"*

> *"Like I preferred it, we had more responsibility, because we learned it ourselves, and I think we will remember more then….like if we got stuck we used the SPS model to help us and the hints on the website which was good"*

The design of the Bridge 21 learning experience including, plan, create, reflect and present allowed gave the students the opportunity to see use their metacognitive skills while problem solving and interacting with the Microworld. Participants seemed to enjoy working on the project and enjoyed the lesson format in the learning activities.

> *Teacher - "Students seem to be really enjoying the learning experience with students laughing and expressing their satisfaction when their solution works"*

> *"This is fun sir, its better using the laptops; you can concentrate more because you are doing it yourself and if we can work together to solve the problems"*

It is important to note however that students had mixed feelings when discussing working together as teams. Code D4: N=14 highlighted that were some negative thoughts on the use of group work in the learning activity. Further analysis from the field notes and focus group interviews reaffirmed these concerns.

> *"Yeah I liked working together in teams, we could share and discuss our ideas and work out the problem together when we got stuck"*

In contrast:

> *"No I don't like the group work, cause everyone relies on each other and nothing gets done properly in the end, like if nobody takes control then nothing gets done"*

Reviewing the researchers field notes, on numerous occasions the researcher acknowledged that the group dynamic was very important on the success of the work rate in each group. In hindsight, the researcher acknowledged that in some groups the personalities of the members clashed or did not suit the group dynamic.

In summary, a participant outlines:

> *"Yeah it depends on who you are working with, if the people are good workers and help then its fine, but if you have to do all the work on your own it is frustrating"*

Despite these concerns reviewing the data collected observational analysis, indicates that the mean class score for effective engagement and participation was 4/5 which suggest there is strong evidence that the students where active and engaged in the learning experience when problem solving which is important.

Similar to limitations outlined for answering research questions above, overall the data appears to suggest the Bridge 21 learning framework had a positive impact on scaffolding the learning experience to insure that students were active learners and this insured that students were engaged in developing their metacognitive skills and problem skills in the learning environment.

5.5 Conclusion

This chapter has presented and discussed the quantitative and qualitative data collection tools used to elicit and present a rich description on the impact of the design of this learning intervention. This study has collected and analysed a series of data that was triangulated to present and discuss the main findings in this study that was used to address the research questions proposed. The findings in this chapter appear to indicate the successful design and incorporation of a SPSM to enhance student's metacognitive skills when problem solving. Results also appear to suggest the affordances of suitable Microworld simulations can allow students to develop their metacognitive and problem solving skills such as critical thinking and creativity interacting with the Microworld. Finally, the chapter outlined the evidence to support the role of the Bridge 21 learning environment appears to enhance student's metacognitive and problem-solving skills by allowing students to construct their own knowledge in a student centred learning environment where students must plan, create, design, present and reflect on their learning experience.

As stated in this study previously, problem solving is not taught in isolation. This study has proven that the SPSM combined with a suitable Microworld when delivered in a 21st century learning environment can have a positive impact on developing students metacognitive skills and problem solving skills.

However, the data did highlight areas for concern with group work. The researcher acknowledged that the group dynamic of the participants is an integral part to the success of the learning activity. The limitations of the data were discussed, but a more detailed summary of these is presented in the final chapter.

Chapter 6: Conclusion

6.1 Introduction

This aim of this dissertation was to investigate the effects on the use of a synthesised problem solving model (SPSM) to enhance students metacognitive skills when problem solving. Inherent to the design of this investigation, three important design elements where investigated to try develop student’s problem solving skills. To address the research questions proposed the researcher designed a learning experience underpinned by these three key elements. Firstly, the design of a Synthesised Problem Solving Model (SPSM) was developed to assess the effect on developing students metacognitive skills when problem solving. Secondly, the role of a highly immersive Microworld simulation was investigated to assess the impact on developing students metacognitive and problem solving skills. Finally, the effect of the Bridge 21 learning model, to allow students to develop and enhance their problem solving skills was examined.

This study has highlighted that problem solving is a complex process with multiple factors to be considered when designing effective problem solving environments. Data collected in this study has highlighted that the SPSM when delivered in a 21st century learning experience with the use of a suitable Microworld can be successful in developing these skills.

This dissertation has successfully addressed the research questions outlined in this study. This research project has discussed and presented how the use of a SPS problem solving model can be used to develop students metacognitive skills when problem solving. The study has also highlighted the affordances of a highly immersive, interactive and engaging Microworld when blended with a 21^{st,} century learning model can be used to allow students develop their problem solving skills. The data analysed indicated a significant increase in student’s metacognitive skills and qualitative data revealed the positive impact on the use of the Microworld when delivered using the Bridge 21 learning model. This chapter will discuss some potential limitations to the research including the small sample size and time duration of the learning experience. Potential areas for further research in this field are discussed including use of various Microworlds to teach various aspects of problem solving and investigating if, presenting the SPSM to primary school students could develop students metacognitive and problem solving skills at an earlier age.

6.2 Main Research Findings.

One main research question and two sub research questions were proposed in this study.

Q1. Does the use of the synthesized problem solving model (SPSM), enhance problem solving skills and metacognitive skills when problem solving.

The purpose of this question is to investigate if explicitly using a SPSM when problem solving can help students to develop and apply their metacognitive skills (planning, monitoring and reflecting) when problem solving.

Q2. Sub Question: What role did the Microworld simulation impact on the process?

The rational for this question is to examine how the Microworld selected can allow students to develop these skills while problem solving.

Q3. Sub Question: What role did the Bridge 21 learning environment on the process?

The aim of this question is to investigate what aspects of the Bridge 21 learning environment affected developing student's problem solving skills.

6.2.1 Effect of SPS Model.

This research indicates that the use of a SPSM can have a positive impact on developing students metacognitive skills specifically skills in planning, monitoring and reflection while problem solving. Statistically significant results were obtained in the analysing the student mean scores on students perceived effective use of metacognitive skills when problem solving.

The positive impact of the SPSM is emphiased in the qualitative data gathered in the study. Independent observations from external mathematics teachers analysing the use of the SPSM found the model to be very effective in the learning activities with students showing ample evidence to indicate the positive impact of the model when problem solving. Similar evidence is evident in the field notes of the researcher and the student artefacts in their solutions to the design of each problem. The model supported and scaffolded student's conversations when attempting to produce a solution.

In addition to the field notes and student artefacts, the focus group interviews provided a rich and deep understanding on the positive views and opinions from the participant's perspectives. Comparing the knowledge of the participants before and after on their metacognitive skills when problem solving appears to indicate a greater knowledge and awareness on the use of planning, monitoring and reflecting while problem solving.

It is important to note that despite these positive effects outlined above, no significant increase was recorded in the difference in mean scores in the PISA problem solving tests. This result is not surprising and the researchers did not expect student's problem solving skills to significantly increase in the short time intervention. The researcher acknowledges that there are a number of variables that effect the development and improvement of student's problem solving skills.

Despite the PISA test scores there is evidence to suggest that the SPSM had a positive impact on enhancing student's metacognitive skills when problem solving. Using the model to teach students, enabled the students to develop their awareness on strategies that can be used when problem solving. Inherent to the model is encouraging students to apply higher order thinking skills and critically interpret the problem to create innovative and creative solutions, which in time, will develop students overall problem solving ability. If the model can assist in helping reduce the working memory load exerted when trying to problem solve then this is a useful of set of skills to develop within students.

6.2.2 Role of the Microworld

This study investigated what role the use of a Microworld simulation could have on developing student's metacognitive skills and problem solving skills. The data collected indicates that the use this Microworld can have a positive effect on allowing students to develop and improve these skills. A number of factors were considered important to outline to role of the Microworld in developing these skills.

Firstly, the qualitative data signifies the important attributes that a highly immersive Microworld can have on developing these skills.

- Visually: The Microworld helps the students to plan, visualise and allows the students to apply the SPSM in sequence to test their design. The Microworld insured that students had to critically analyse the problem first, design and create a solution and then test the solution that allowed the students to develop their metacognitive and problem solving skills.

- Constructionist: The constructionist features of the Microworld allowed the students to develop and display their creativity and critical thinking skills by creating and designing their ideas that represented their understanding of the problem.
- Reflection: An important feature that assisted in the development of students metacognitive skills was the affordance of the software to present to the students their design, which highlighted the specific load test analysis for their design. This enabled students to reflect, review and amend their design to match the criteria of the problem.
- Creativity: The Microworld allowed students to develop their higher order thinking skills by allowing for a multiple of design features that enabled the students to express their creativity.
- Maths and Physics: The Microworld allowed the students to interact and explore the fundamentals of bridge design, material that requires a high-level of knowledge. The Microworld allowed the students to discover the principal relationships through interacting with the Microworld.
- Enjoyable and Engagement: The Students revealed that interacting with the Microworld as an enjoyable experience. Student's attitudes towards problem solving with Microworlds such as this one were positive.

Evidence to support these findings is echoed in the observational analysis on the effective use of Microworld in the learning activity. Overall, the data collected in this study indicates that the Microworld was a useful tool and important design feature to all students to develop their metacognitive and problem solving skills. Comparing the data collected with previous research on Microworlds, similarities are evident, highlighting the potential use of Microworlds in learning environments.

6.2.3 Role of the Bridge 21 Learning Environment

The final research question proposed in this study was to examine the role the Bridge 21 learning framework in developing student's metacognitive skills when problem solving. The data gathered in this project suggests the positive impact for the use of the Bridge 21 learning framework to allow students develop these skills. The data revealed that a number of features of the Bridge 21 model allowed for this:

- The emphasis on a student centred learning environment where students are actively involved in the knowledge process allowed for students to be engage in the learning activities.
- The scaffolded teacher approach allowed students to become responsible and accountable for their work, which had a positive impact on student participation where they could develop these skills.
- Students had mixed responses on the positive impact of group work. The researcher acknowledges that group dynamic in some groups was not as effective as others were. For the majority students enjoyed the idea that could share, plan, develop and discuss the problem as a group, hence developing their metacognitive skills.
- Observational analysis displayed that levels of participation and engagement in the learning activity was high.
- The steps involved in the bridge 21 learning model encouraged students to apply their metacognitive skills whilst using the SPS model. Inherent to the model is to allow students the opportunity to plan, create, design, reflect and present. These opportunities gave the students an opportunity to develop there metacognitive and problem solving skills.

In general, the use of the Bridge 21 Learning model had a positive role in allowing students to develop and enhance their metacognitive and problem skills throughout the learning activity. These findings are similar to research conducted on the effectiveness of the model to enhance student engagement and develop intrinsic motivation within students.

6.3 Limitations to the Research

The researcher acknowledges that there are a number of limitations to the research and the results presented in this study are indicative of the participants involved in this study. The researcher will present some limitations to the research conducted in this study.

- Time and Sample Size: The duration of this learning experience lasted only 3 weeks with the learning experience totalling 8-10 hours. This learning intervention in comparison with the amount contrasting learning experiences students are exposed to daily is very small. A longer and more detailed learning experience would be required to provide further evidence. Ideally, a larger sample size would provide a more detailed analysis on the impact of the learning intervention.

- Nature of the Participants: The researcher chose a convenience sample as the participants where in the researcher's school. The researcher acknowledges this may present bias in that data collected. Ideally, a larger, more diverse set of participants would be chosen to provide a broader perspective on the impact of the study.
- Enhancing Problem Solving Skills: The researcher acknowledges that developing ones problem-solving skills is not straightforward. There are numerous factors and variables to becoming an efficient and effective problem solver. This project specifically only addressed one particular factor when problem solving. To be able to accurately describe the full effect of the SPS model, numerous other factors would have to be investigated.
- Small Area/Topic investigated: The topic of Bridge design was chosen to develop student's problem skills as participants would have no prior background knowledge. Ideally, the SPS model could be tested with other subjects and a variety of problem solving contexts to investigate is impact.

6.4 Areas for Further Research

The researcher intends to investigate some further areas of research that would provide a broader and deeper insight into the use of the SPS model in developing students metacognitive and problem solving skills.

- Younger Participants: The researcher would like to investigate the effect of delivering the SPS model to primary school students. Problem solving can be a frustrating and annoying process for students, which can have a negative influence on student's perception of maths and problem solving in general. It would interesting to investigate students had developed a high standard of metacognitive skills at an early age what affect would this have on students level of problem solving skills across all contexts.

- Microworlds Suitable for Problem Solving: The affordances of suitable technology have been discussed in detail in this study. The researcher would like to researcher further Microworlds that are suitable for allowing students to develop their problem solving skills in a multitude of contexts. Research has indicated to that technology can have positive effects in learning environments and can enhance student participant and engagement. If educators could successfully incorporate technology in the learning activities, this could have a positive effect on the quality of education delivered.

6.5 Conclusion

This exploratory case study has presents a detailed discussion on the findings that addresses the research questions proposed in this study. This dissertation has successfully highlighted the positive effect of using a SPSM on developing students metacognitive skills while problem solving. It has also highlighted the positive role of Microworlds when combined in a 21st learning environment to foster and improve these skills. In summary the use of the SPSM, with an appropriate Microworld, delivered as part of a 21st century learning activity can have a positive influence on student's metacognitive skills and problem solving skills. Problem solving is not taught in isolation and this study has highlighted one potential method of developing these skills.

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Appendices 1: Design Table

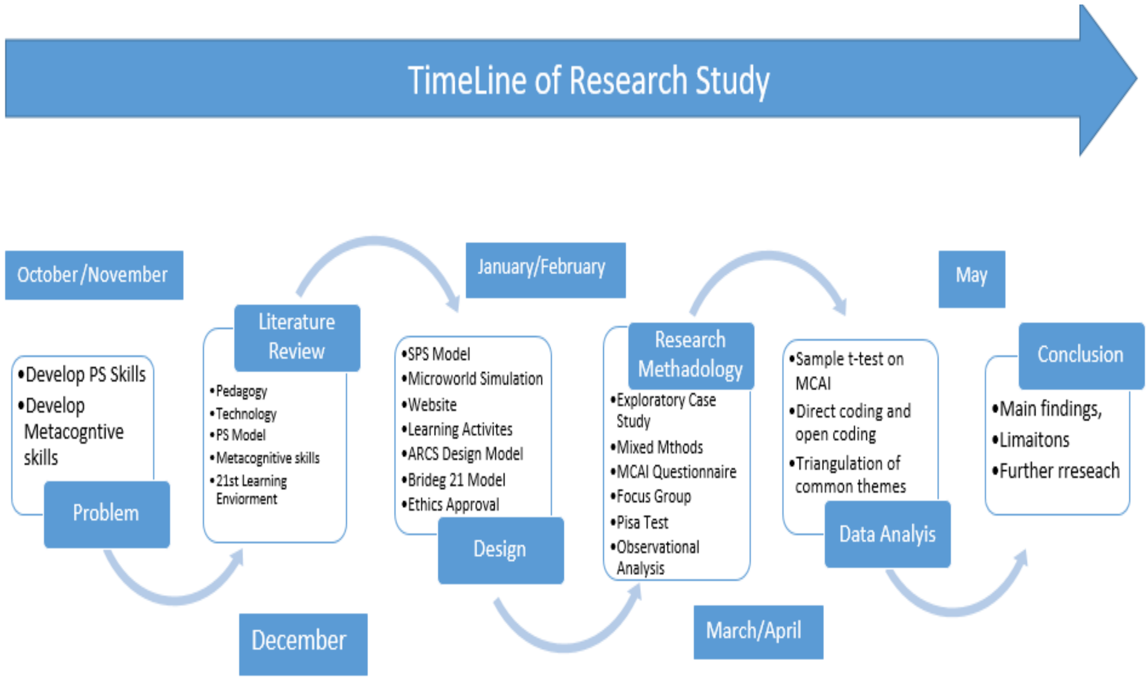
Literature Review Theme	Design Principles	Design Implementation	Anticipated Outcome
Pedagogical Approach:	**Constructivism & Social Constructivism** ➢ Students working and learning together in the form of group work and collaboration. Students share and discuss their ideas and knowledge and learn from each other to develop their understanding. ➢ Zone of Proximal Development (ZPD), the process of learning from peers and more abled others.	➢ Students work in groups of 2-3. ➢ Students will share, discuss, plan and reflect with each other throughout the learning experience.	➢ Students learn from each and share ideas. ➢ Students are engaged and active in the learning experience.
(Piaget , 1955) (Piaget & Inhelder, 1967) (Vygotsky, 1978) **(Papert, 1980) (Papert & Harel, 1991)**	**Constructionism** ➢ Students can create artefacts to represent the learning intentions of an activity. The artefact allows the student to demonstrate their understanding. ➢ Students are actively involved in the learning process.	➢ Students must create an artefacts that showcases their understanding, ➢ Learning activities are designed to be student centred.	➢ Students become responsible for their learning. ➢ Students present their work demonstrating their levels of understanding.
Problem Solving Approaches **(Polya, 1981) (Resnick & Glaser, 1976) (Treffinger & Isaksen, 2005)**	**Problem solving Models** ➢ Frameworks established to assist in problem solving. ➢ Emphasises the importance of being able to deconstruct and reconstruct the solutions to the problem. ➢ "Understanding the problem, devising a plan, carry out the plan and look back" ➢ "Problem Detection, feature scanning and goal analysis" ➢ Importance of the metacognition process when problem solving	➢ Design of the problem-solving framework must help the student to navigate through a problem. ➢ Clear steps and goals need to be outlined for each stage in the framework.	➢ Students successfully use the framework to help them address problems. ➢ Students understand the process of deconstructing and reconstructing ideas. ➢ Students become more confident and efficient

(Schoenfeld, 1985)			problem solvers.
Computational Thinking (Wing, 2006) (Kalelioglu et al., 2016)	**Computational Thinking:** ➢ Cognitive process involved when using computers in problem solving. ➢ “Decomposition, Pattern recognition, Abstraction, Algorithm Design ➢ CT Framework to guide students though the problem solving process. ➢ Process of higher level thinking when problem solving.	➢ Incorporate aspects of the CT framework in the problem-solving model. ➢ Compare and contrast how computers and students problem solve.	➢ Students develop their computational thinking skills. ➢ Students successfully utilise technology to assist them in the problem solving process.
Developing Metacognitive Skills	**Metacognition:** ➢ Developing an awareness and understanding of your cognitive activities in a learning activity. ➢ Metacognitive skills involved in planning, sequencing and validating an outcome in problem solving.	➢ Learning activity will encourage the student to reflect and review the skills, steps, and beliefs that they used to address the problem. ➢ Teacher will explain the importance of metacognition to develop their learning skills.	➢ Students enhance their metacognitive skills and attitudes towards problem solving. ➢ Students apply the skills they have learned across all aspects of learning.
(Veenman, Van Hout-Wolters, & Afflerbach, 2006) (Brown, 1978) (Flavell, 1979) (Kroll , 1988)	**Metacognition in Problem Solving:** ➢ Framework to monitor the behaviour and roles of students in collaborative problem solving environments.	➢ Students must analyse their behaviour in the learning activity.	➢ Students appreciate the importance of metacognitive skills when learning.
Realistic Maths Education	**Realistic Maths Education:** ➢ Encourages students to apply their experiences, intuitions and commons sense to develop the mathematical knowledge and problem solving skills.	➢ Students must be able to relate to the learning activity. ➢ Learning activity needs to be student centred.	➢ Students use experiences and skills when and apply common sense when problem solving.

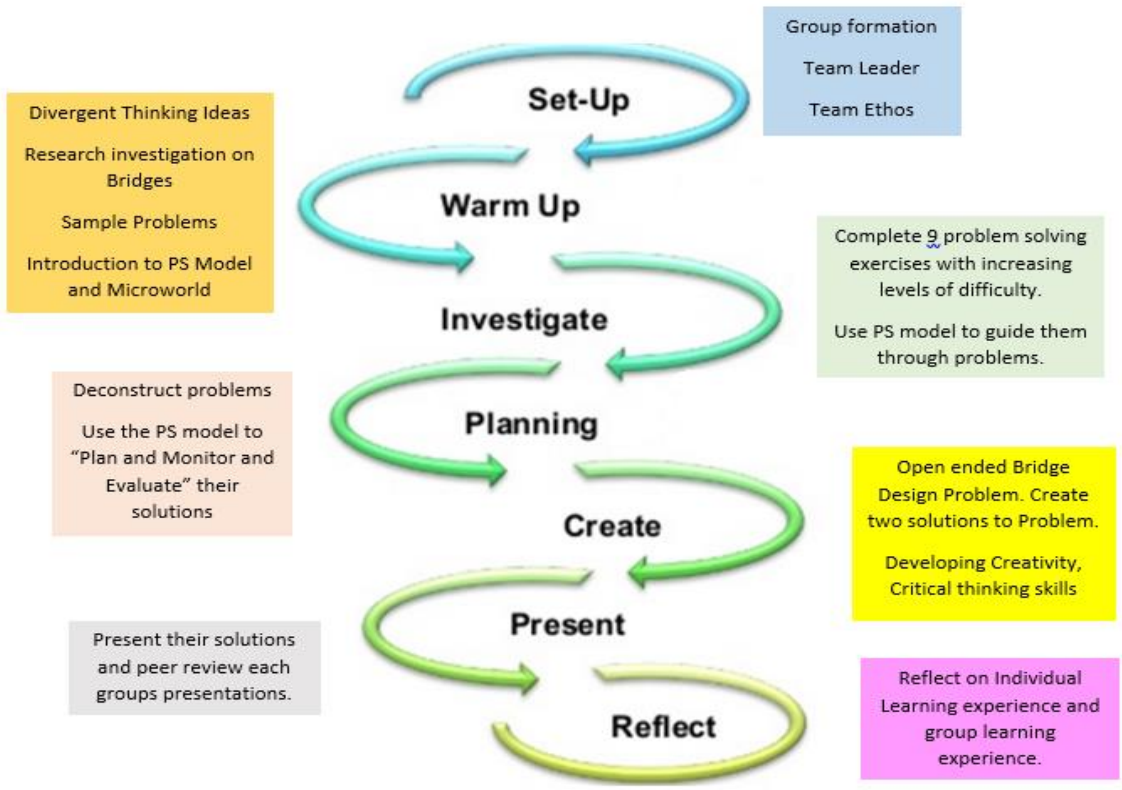
(Bray & Tangney, 2015) (Freudenthal, 1991)			
Incorporation of Technology **SAMR Model (Puentedura, 2006, 2009,2013)**	**Use of ICT in Learning Activity** ➢ Different levels of incorporation of ICT in learning activities.	➢ To redefine the learning experience and to allow for effective constructionism, technology must allow perform tasks that would not be possible without it.	➢ Student use the technology effectively and are engaged in the learning process. ➢ Students perform tasks that would be difficult without the use of technology
	Pedagogical Approaches with ICT: ➢ The incorporation of Technology in learning activities is beneficial when incorporated with constructive and constructionist pedagogies that promote active learning.	➢ Learning activities and technology must allow for collaboration and cooperation between students.	➢ Students work effectively through group work to share, discus and successfully operate the technology to its full potential in the learning activities.
(Bray & Tangney, 2016) (Voogt & Pelgrum, 2005) **(Fang & Guo, 2016)**	**Benefits of Technology:** ➢ The affordances of technology when incorporated in maths and engineering education to explain and display the inherent properties and underline principles in a topic. ➢ The technology has the capacity to connect the learner to the context of the learning environment where students can test, implement and reflect on their ideas to create meaning and develop understanding.	➢ Insure the technology accurately displays the real life properties of the topic. ➢ Technology selected must be user friendly and should allow the students to manipulate the variables and adjust the controls.	➢ The Students use the technology to investigate and interact with the underlying principles and relationships inherent to the topic. ➢ Student’s level of understanding is enhanced because of interacting with the technology.

(Hoyles, 2016) **(Edwards , 1995)** **(Rieber, 2005)**	**Microworlds:** ➢ Dynamic and interactive, exploratory learning environments.	➢ The Microworld selected must all the students to explore and interact with the underlying relationships.	➢ Students navigate through the Microworld while developing their knowledge and problem solving skills.
21st Century Learning Model **Bridge 21 Learning Model** **(Fullan & Langworthy, 2013)** **(Ncca, 2011)** **(Dede, 2010)** **(Pence, 2010)** **(Voogt & Roblin, 2012)** (Conneely et al., 2012)	**21st Century Learning Environment:** ➢ Developing educational settings to develop and prepare students for the 21st Century, which will result in the growth of 21st century skills. ➢ The importance of creating 21st century learning framework that creates partnerships of learning between the teachers and students that will result in a deeper learning experience.	➢ Teacher scaffolds the learning environment with activities designed to promote student activity and engagement. ➢ Students are responsible for their own learning.	➢ Students enjoy and are engaged in the learning experience while learning. ➢ Students develop ownership for their work, which engages them in the learning activity. ➢ Students develop their 21st century skills.
	21st Century skills: ➢ The skills that students need to practise and develop. “collaboration, communication, ICT literacy, social and cultural skills, critical thinking and problem solving skills”	➢ The learning activities and problems solving exercises will require the students to apply 21st century skills.	➢ Students are active in the learning environment and developing their 21st century skills.
	Bridge 21 Framework: ➢ A 21st century learning framework that has been proven as a successful framework for the incorporation of technology and group work while developing 21st century skills.	➢ The Bridge 21 model is used to design the learning activities in the investigation.	➢ Students collaborate to solve problems with the use of technology in a traditional classroom setting.

Appendices 2: TimeLine of Research Study



Appendices 3: Design of Lesson using Bridge 21 Framework



Appendices 4: MCAI Questionnaire

This questionnaire is designed to collect information on your problem solving process. Please read the following questions carefully and answer all questions truthfully. Circle a value from 1 (never) to 5 (Always) for each for statement to describe the way you are when trying to solve a problem. Please refer to the method you used when attempting the problem-solving pre-test.

Survey Scale: 1 = Never….5 = Always.

Name: ________________ Date: ________________

Questionnaire	Never	Rarely	Sometimes	Often	Always
1. I read the statement of a problem carefully to fully understand it and determine what the goal is.	1	2	3	4	5
2. When I do assigned problems, I try to learn more about the concepts so that I can apply this knowledge to test problems.	1	2	3	4	5
3. I sort the information in the statement and determine what is relevant.	1	2	3	4	5
4. Once a result is obtained, I check to see that it agrees with what I expected.	1	2	3	4	5
5. I try to relate unfamiliar problems with previous situations or problems solved.	1	2	3	4	5
6. I try to determine the form in which the answer or product will be expressed.	1	2	3	4	5
7. If a problem involves several calculations, I make those calculations separately and check the intermediate results.	1	2	3	4	5
8. I clearly identify the goal of a problem (unknown variable to solve for or the concept to be defined) before attempting a solution.	1	2	3	4	5
9. I consider what information needed might not be given in the statement of the problem.	1	2	3	4	5
10. I try to double-check everything: my understanding	1	2	3	4	5

of the problem, calculations, units, etc.					
11. I use graphic organizers (diagrams, flow-charts, etc.) to better understand problems.	1	2	3	4	5
12. I experience moments of insight or creativity while solving problems.	1	2	3	4	5
13. I jot down things I know that might help me solve a problem before attempting a solution.	1	2	3	4	5
14. I find important relations among the quantities, factors, or concepts involved before trying a solution.	1	2	3	4	5
15. I make sure that my solution actually answers the question.	1	2	3	4	5
16. I plan how to solve a problem before I actually start solving it (even if it is a brief mental plan).	1	2	3	4	5
17. I reflect upon things I know that are relevant to a problem.	1	2	3	4	5
18. I analyze the steps of my plan and the appropriateness of each step.	1	2	3	4	5
19. I attempt to break down the problem to find the starting point.	1	2	3	4	5
20. I spend little time on problems for which I do not already have a set of solving rules or that I have not been taught before.	1	2	3	4	5
21. When I solve problems, I omit thinking of concepts before attempting a solution.	1	2	3	4	5
22. Once I know how to solve a type of problem, I put no more time in understanding the concepts involved.	1	2	3	4	5
23. I do not check that the answer makes sense.	1	2	3	4	5

24. If I do not know exactly how to solve a problem, I immediately try to guess the answer.	1	2	3	4	5
25. I start solving problems without having to read all the details of the statement.	1	2	3	4	5
26. I spend little time on problems I am not sure I can solve.	1	2	3	4	5
27. When practicing, if a problem takes several attempts and I cannot get it right, I get someone to do it for me and I try to memorize the procedure.	1	2	3	4	5

Appendices 5: Observational Data Tool

This is the observation tool used by teachers in the learning activity.

Observational Checklist

Use the following checklist to assess the level of evidence demonstrated by each group to under the following themes and criteria.

Group Name: ________________________ Date: _______________

Use of the Synthesized PS Model					
Criteria ***No Evidence:*** Poor no use of SPS model ***Poor Evidence:*** Some use of the strategy but no plan established. ***Average Evidence:*** Plan established however deviates from plan. ***Good Evidence:*** Applied all stages in the SPS Model ***Excellent evidence:*** Excellent use of the SPS model. Excellent examples of creativity, problem solving and reflection.	No Evidence	Poor Evidence	Average Evidence	Good Evidence	Excellent Evidence
Use of The technology with Synthesised PS Model					
Criteria ***No Evidence:*** Poor didn't use the technology correctly. ***Poor Evidence:*** Some use of the software, but low level of success with problem solving. ***Average Evidence:*** Some good use of the software to address the problem solving questions. ***Good Evidence:*** Used the software to produce solutions to the problem solving questions. ***Excellent evidence:*** Uses the software to produce excellent solutions to the problems presented.	No Evidence	Poor Evidence	Average Evidence	Good Evidence	Excellent Evidence

Participation/Engagement in the Learning Environment					
Criteria ***No Evidence:*** no effort put into the learning activity ***Poor Evidence:*** Some use of software, poor interaction with fellow students. ***Average Evidence:*** Average participation levels in the learning activity. ***Good Evidence:*** Engaging well with the learning activity. Solving the problems and using the software and CT skills. ***Excellent evidence:*** Uses the software to produce excellent artefacts to support their arguments.	No Evidence	Poor Evidence	Average Evidence	Good Evidence	Excellent Evidence

Any other observational data relevant to the learning experience?

____

____

____

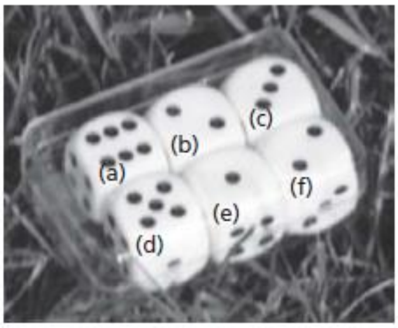
Total Score: ________________________

Appendices 6: Sample PISA Questions Pre and Post Test

In this photograph you see six dice, labelled (a) to (f). For all dice there is a rule:

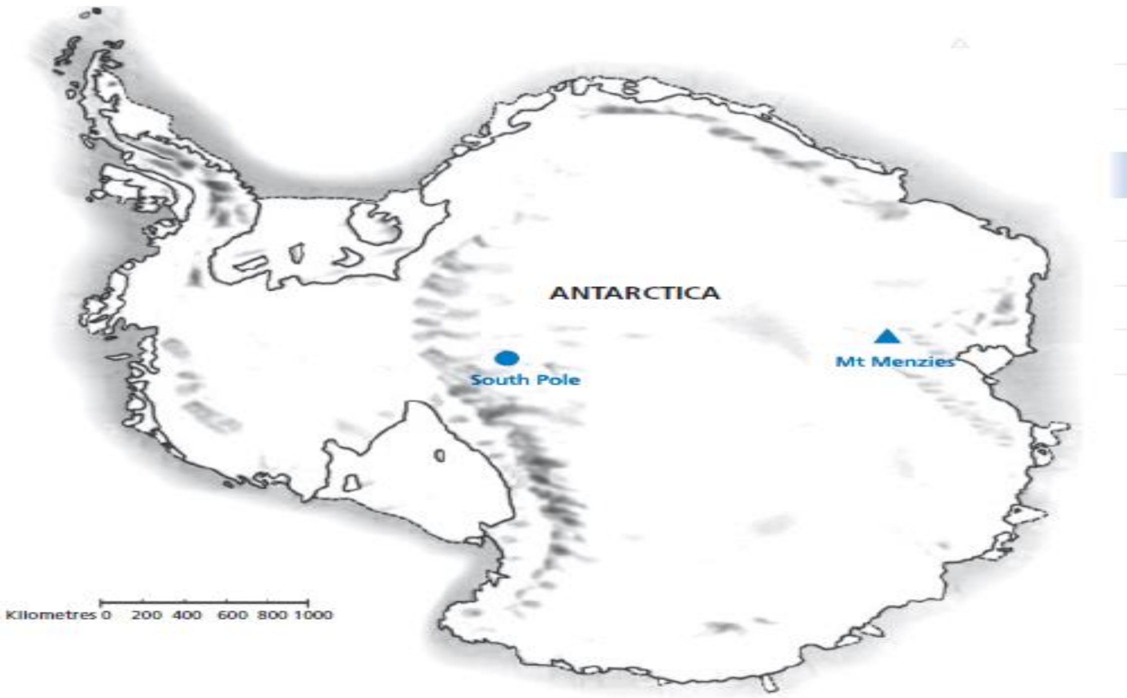
The total number of dots on two opposite faces of each die is always seven.

Write in each box the number of dots on the *bottom* face of the dice corresponding to the photograph.



(a)	(b)	(c)
(d)	(e)	(f)

Question 2:



QUESTION 5.1

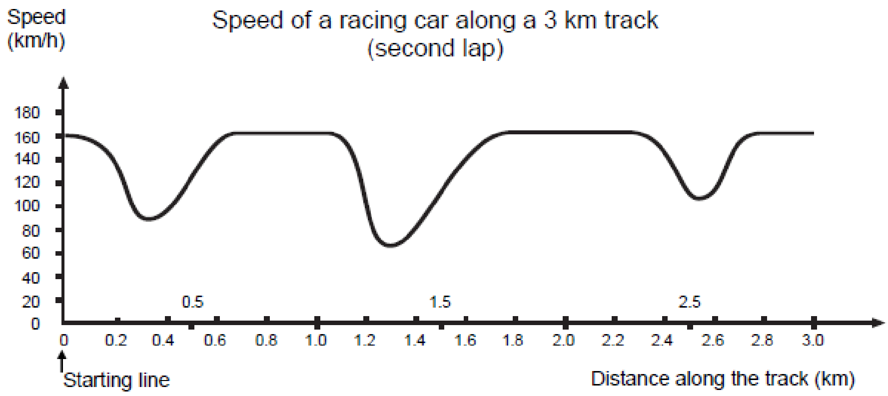
Estimate the area of Antarctica using the map scale.

Show your working out and explain how you made your estimate. (You can draw over the map if it helps you with your estimation)

....

M159: Speed of Racing Car

This graph shows how the speed of a racing car varies along a flat 3 kilometre track during its second lap.



Question 1: SPEED OF RACING CAR

M159Q01

What is the approximate distance from the starting line to the beginning of the longest straight section of the track?

Question 3:

What is the approximate distance from the starting line to the beginning of the longest straight section of the track?

A 0.5 km
B 1.5 km
C 2.3 km
D 2.6 km

Where was the lowest speed recorded during the second lap?

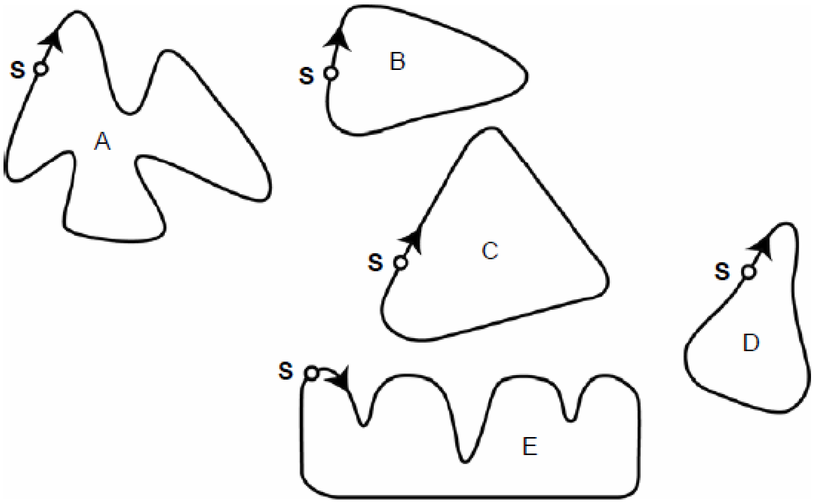
A. at the starting line.
B. at about 0.8 km.
C. at about 1.3 km.
D. halfway around the track.

What can you say about the speed of the car between the 2.6 km and 2.8 km marks?

A. The speed of the car remains constant.
B. The speed of the car is increasing.
C. The speed of the car is decreasing.
D. The speed of the car cannot be determined from the graph.

Here are pictures of five tracks:

Along which one of these tracks was the car driven to produce the speed graph shown earlier?



S: Starting point

Appendices 7: Interview Questions

Interview Questions:

A selection of questions were asked in the interviews from each section.

Learning Experience:

1. How did you find the project? Did you like it? Did you think you learned anything from doing the project?
2. Have you learned anything about how to problem solve when doing the project.
3. Do you think you learned any new skills or developed any new skills?
4. What are your thoughts on the problem-solving model? Did you use it? Did it help you in any way?
5. Do think that you had use the following skills, plan, review and monitor when doing the project?
6. What did you think of the software, did you like it, did you think it was good to use technology when problem solving?
7. Do you think the project made you to think critically think, and be innovative?
8. Did you like working together in teams? If so Why/Why not. What did you think was good/bad about learning in teams?
9. How did find the support from the website? Did you think it influenced you in the project?
10. Did you find the project interesting? If so Why/Why not? Could you give me an example what you found the most/least interesting in the project?
11. What do you think you learned from doing the project? Do you think you learned any new content or any new Skills?
12. Do you think how you learned in this project was different? If so why/why not? What did you think about learning this way?

Technology Questions:

1. Did you use much technology in this project? If so which technology did you use? What did you like about the technology?
2. Do you think the technology helped you to learn in this project? If so why/why not and How? Could you give me examples of how the technology did/did not help you?
3. What features of the technology did you enjoy? Do you think these features effected how you learn? If so why/why not?
4. What technology did you use to present your projects? How did find this difficulty or easy and explain why?

5. Did you like using technology in the classroom? If so why/why not? Do you think teachers should use more technology in the classroom?
6. How did you find working with the technology as a group? Was it difficult/easy if so how?

Problem Solving

1. What aspects of Problem solving do you find easy/difficult?

2. What was your experience of the learning activities? What did you like or dislike?

3. Did you like or dislike using the Bridge Design Technology? If so what parts?

4. How did you find the working together in the Bridge 21 model?

5. Do you think you learned any strategies on how to become a better problem solver?

Appendices 8: Timeline of Ethics Approval

Wednesday, February 8, 2017 - 17:31
State change:
from *Commented by Reviewers; Pending REC Meeting*
to ***Approved***

Wednesday, February 8, 2017 - 17:31
State change:
from *Assigned to Reviewers; Pending Comments*
to ***Commented by Reviewers; Pending REC Meeting***

Wednesday, February 8, 2017 - 15:12
State change:
from *Submitted to REC; Awaiting Reviewer Assignment*
to ***Assigned to Reviewers; Pending Comments***

Wednesday, February 8, 2017 - 15:12
State change:
from *Submitted to Supervisor; Pending Review*
to ***Submitted to REC; Awaiting Reviewer Assignment***

Wednesday, February 8, 2017 - 14:32
State change:
from *REC Amendments Required*
to ***Submitted to Supervisor; Pending Review***

Tuesday, February 7, 2017 - 15:50
State change:
from *Commented by Reviewers; Pending REC Meeting*
to ***REC Amendments Required***

Friday, January 20, 2017 - 09:53
State change:
from *Assigned to Reviewers; Pending Comments*
to ***Commented by Reviewers; Pending REC Meeting***

Friday, January 20, 2017 - 09:41
State change:
from *Submitted to REC; Awaiting Reviewer Assignment*
to ***Assigned to Reviewers; Pending Comments***

Friday, January 20, 2017 - 09:41
State change:
from *Submitted to Supervisor; Pending Review*
to ***Submitted to REC; Awaiting Reviewer Assignment***

Thursday, January 19, 2017 - 16:39
State change:
from *REC Amendments Required*
to ***Submitted to Supervisor; Pending Review***

Wednesday, January 11, 2017 - 11:34
State change:
from *Commented by Reviewers; Pending REC Meeting*
to ***REC Amendments Required***

Appendices 9: Ethics Form

Project Title: As part of a 21st century learning activity an Investigation into the effect of applying computational strategies when using bridge simulation technology on enhancing problem solving skills in Maths Education.

Name of Lead Researcher (student in case of project work): Ian Boran

Name of Supervisor: Brendan Tangney

TCD E-mail: borani@tcd.ie Contact Tel No.: +353851109940

Course Name and Code (if applicable): MSc. in Technology and Learning

Estimated start date of survey/research: 1/1/2017

I confirm that I will (where relevant):

- Familiarize myself with the Data Protection Act and the College Good Research Practice guidelines

http://www.tcd.ie/info_compliance/dp/legislation.p

- Tell participants that any recordings, e.g. audio/video/photographs, will not be identifiable unless prior written permission has been given. I will obtain permission for specific reuse (in papers, talks, etc.)
- Provide participants with an information sheet (or web-page for web-based experiments) that describes the main procedures (a copy of the information sheet must be included with this application)
- Obtain informed consent for participation (a copy of the informed consent form must be included with this application)
- Should the research be observational, ask participants for their consent to be observed
- Tell participants that their participation is voluntary
- Tell participants that they may withdraw at any time and for any reason without penalty
- Give participants the option of omitting questions they do not wish to answer if a questionnaire is used
- Tell participants that their data will be treated with full confidentiality and that, if published, it will not be identified as theirs
- On request, debrief participants at the end of their participation (i.e. give them a brief explanation of the study)
- Verify that participants are 18 years or older and competent to supply consent.
- If the study involves participants viewing video displays then I will verify that they understand that if they or anyone in their family has a history of epilepsy then the participant is proceeding at their own risk
- Declare any potential conflict of interest to participants.
- Inform participants that in the extremely unlikely event that illicit activity is reported to me during the study I will be obliged to report it to appropriate authorities.
- Act in accordance with the information provided (i.e. if I tell participants I will not do something, then I will not do it).

Signed: .... Date: 09/11/2016

Lead Researcher/student in case of project work

Research Project Proposal:

Title:

As part of a 21st century learning activity an investigation into the effect of applying computational strategies when using bridge simulation technology on enhancing problem solving skills in Maths Education.

Purpose of Project including Academic Rationale.

I am currently a 2nd year student in the MSc in Technology and Learning postgraduate course. A requirement of this course is that the student must produce a dissertation in which the student must conduct research involving the implementation of technology in an educational setting.
From the course handbook of MSc in Technology and Learning 2016:

"The aim of the dissertation is to develop students' research and writing abilities via a substantial piece of independent work. Further, it aims for learners to demonstrate proficiency in the design of a research paper, application of appropriate research methods or approaches, collection and analysis of data and/or relevant literature, and application of area-specific theories and concepts. Students are expected to formulate their own research question (with the guidance of their supervisors), to gather and select material to answer their question, and set out their findings in an academic style. The research project has to involve the design, development and evaluation of a technologically mediated teaching & learning experience. It is expected that the dissertation will be of a publishable standard."

The purpose of this piece of research is measure and investigate the use of technology on the impact of student's attitudes and behaviour and performance in problem solving in mathematics. The introduction of the Project Maths into the Junior and Leaving Certificate Mathematics programme in Ireland has outlined that a core aim of the programme is to develop problem solving skills and abilities within the student cohort.
"Project Maths represents a philosophical shift in Irish post-primary education towards an investigative, problem-focused approach to learning mathematics, emphasising its application in real-life settings and contexts"(Jeffes et al., 2013)
http://www.nfer.ac.uk/publications/NCCB01/NCCB01.pdf

With the introduction of the new Junior Cycle in Ireland in 2011, one of the eight key statements of learning emphasises that students are given opportunity in education to develop creativity and innovation. The new junior cycle reform produced 24 key statements of learning. The following statements of learning are of particular relevance and importance to this research project.
LS 4: Recognises the potential uses of mathematical knowledge, skills, and understanding in all areas of learning.
LS 5: Use mathematical knowledge, reasoning and skills in devising strategies for investigating and solving problems.
LS 6: Describes, illustrates, interprets, predicts and explains patterns and relationships.
LS 7: Improves their observation, inquiry and critical thinking skills.
LS 14: Takes initiative, is innovative and develops entrepreneurial skills.
LS 15: Uses appropriate technologies in meeting a design challenge.
LS 16: Applies practical skills as they develop models and products using a variety of materials and technologies.
LS 17: Creates, presents and appreciates artistic works.
LS 18: Brings an idea from conception to realisation.

LS 19 Uses ICT effectively and ethically in learning and in life. http://ncca.ie/framework/doc/NCCA-Junior-Cycle.pdf

With the development of the digital advances in education and society, research into the reform in how education settings and learning outcomes are delivered has been conducted world-wide. The use of a 21st century learning model to encourage and facilitate deeper and more meaningful learning will be implemented in this piece of research to address the growing demands on preparing students for the 21st century workforce. This dissertation will investigate the use of the Bridge 21 learning model created and designed in Trinity college Dublin to deliver the learning intervention in a 21st century learning model. http://bridge21.ie/about-us/our-model/

In my research project my rational will be to address the following issue:

Investigate the impact on the use of Bridge Design Software https://bridgecontest.org/resources/download/

- An investigation into developing computational skills and strategies when solving problems. This research will investigate the impact on exposing participants to computational thinking strategies when solving problems through a series of learning activities involving open and closed ended problems.
- The research will investigate the role and effect that technology can have on applying computational thinking skills whilst problem solving when using a software that allows for creativity and innovation.
- The technology will serve as a platform for the students to develop their problem solving skills and strategies by engaging in a series of learning activities that involve bridge design and construction.

What the participants will be doing:

- The learning experience is designed to develop critical thinking and innovation as-well as developing the student's problem solving skills.
- The participants will work together in teams to experience the computational thinking process behind by problem solving.
- The participants will then apply these skills they have learned while solving problems using bridge design technology.

Research Questions:

1. Can the use of computational thinking strategies enhance problem solving skills.
2. Can the use of computational thinking strategies be enhanced when incorporating Bridge Simulation software to develop student's skills in problem solving?
3. Can the use of technology impact on developing problem solving skills?

Brief Description of the Methods and Measurements to be used:

The design for this research investigation will be an exploratory case study incorporating a mixed methodology approach for collecting and recording data. A series of qualitative and quantitative data will be collected in this research project.

- Qualitative: Students will participate in a pre and post-test problem solving test to measure their individual problem solving abilities before the learning intervention and after the learning intervention. Attached in the proposal are a series of sample questions that are designed by PISA.

https://www.oecd.org/pisa/pisaproducts/Take%20the%20test%20e%20book.pdf
https://www.oecd.org/pisa/test/testquestions/question1/

- Qualitative: A questionnaire will be delivered to the students before and after the learning intervention to measure student's attitudes towards problem solving. See appendices for questionnaire.
- Quantitative: The researcher will conduct a semi-structured focus group interview with 6-8 participants involved in the learning experience. The interview will be serve to provide an insight into the student's perceptions and attitudes to the learning intervention. The interview will be transcribed and the audio recording will be deleted after the approval of the dissertation by the relevant examination board. The interview questions are attached in this proposal.
- Quantitative: Observations of the learning experience will be conducted to record the student interactions and behaviour throughout the learning experience. A record observation sheet will be completed by the researcher. A copy of the observational Checklist is attached.

Participants - recruitment methods, number, age, gender, exclusion/inclusion criteria, including statistical justification for numbers of participants.

Recruitment:
The participants chosen for this research project are a convenience sample as the participants are students in the school in which the researcher works. Students from the school will be invited to participate in an after school STEM club. Participation in the research project is voluntary. Students may wish to participate in the learning experience without participating in the research project. Parental consent must be granted to all students who volunteer to participate in the research investigation.

Number:
20-30 students
Age:
14-16 years old (any student from Transition year is welcome to join the STEM Club)

Gender:
Mixed, Male and Female.

Exclusion/Inclusion Criteria:
All students who are interested in STEM activities are invited to participate in the afterschool club. Students who do not wish to participate in the research project can still participate in the STEM activities, however they will not be asked to participate in any of the data collection methods. Students are at all times open to question or exclude themselves from the research at any stage during the investigation.
Statistical Justification for Number of Participants:
This research investigation will apply an exploratory and explanatory case study approach. To gather information to address the research questions a mixed methodology of data collection will be used to collect data. (Creswell, 2009) *in Research Design* outlines that the number of participants involved in the research investigation must be large enough to give a true and accurate representation of the experience.

Debriefing Arrangements:

The Principle, Board of Management, Parents, and students will be informed at the start of the research project what the intentions of the project are for. I will outline to the participants that I am conducting a piece of research as part of my degree in MSc in Technology and Learning in Trinity College Dublin. All parties involved will be informed that the data collected in this research project will be used in the researcher's dissertation.

Participants will be informed that the project is intended to improve their problem solving abilities and performance in answering problem solving questions. Developing and enhancing these skills will be vital to improving their mathematical and education skills when it comes to examinations. Problem solving is an integral part of the project maths syllabus and student's learning in a 21st century learning environment is central to the new NCCA junior cycle curriculum. All participants will be notified and informed to the relevance and applications of the research project in their day to day educational experience. *http://ncca.ie/framework/doc/NCCA-Junior-Cycle.pdf and http://www.ncca.ie/en/Curriculum_and_Assessment/Post-Primary_Education/Project_Maths/Project_Maths_developments.pdf*

All parties will be made aware of the time commitments prior to agreeing to participate in the research project. Participation in the research project is voluntary, however it will be made clear that at any stage throughout the duration of the research project that any participant can decide not to participate or withdraw any comments or data they do not want to be used in the dissertation.

Participants will be encouraged to ask any questions and raise any concerns they have throughout the research project. Following analysis of the data, students, parents, teachers and members of the board of management of the school will be informed of the outcomes of the project and will be available to view the dissertation.

When conducting the data collecting each participant and parent will be given an information sheet on why data is being collected. The data collected in this research project will aim to investigate student's attitudes, beliefs and performance in problem solving.

Conflict of Interest Statement:

The researcher in this dissertation teaches the participants in the school at which the researcher works. Due to this there, a conflict of interest may arise. I am aware that as I am approaching students that I teach students may feel compelled to answer interview questions in a certain way and may not be comfortable. In such a scenario, I will ask another designated teacher to conduct the interview. Students will be made aware that their responses will be treated with confidentiality and anonymity.

The researcher will adhere to proper researcher guidelines and codes of conduct when conducting the investigation.

A clear concise statement of the ethical considerations raised by the project and how you intend to deal with them:

<u>Ethical Consideration Number 1: Participants are Under 18</u>

This research investigation will involve participants under 18 years of age.
The following considerations will be taking into consideration when the participants take part in the project.

1. Anonymity: The profile of the students will remain anonymous in a recording any information that is disclosed in the project. The researcher will not use the students name or personal details in the project report.
2. Confidentiality: The researcher will promise confidentiality to any of the information disclosed in the focus group interview. The data collected will be non-traceable to any of the students, so that the response of any individual cannot be traced. The researcher will be only interested in behaviour of the students in the learning episode.
3. Recruitment: Participation in STEM club and research investigation in voluntary. Students who want to join the club with the permission of their parents are allowed to do so. Students interested will sign up to the club via a notice on the school notice board. All students who wish to participate in the research project must attain constant from their parents. Any student who does not want to participate in the research investigation but does want to participate in the STEM club will carry out the same activities as all students however no data will have collected on these students and no participation is required by these students in data collection methods, these students will conduct the learning activates under the supervision of another teacher in another classroom.
4. Participants will be allowed to review the transcripts of the interview.
5. Privacy: The researcher will insure the privacy of the children is upheld throughout the project. No information regarding personal details about the students will be asked or used in the project. Participants will be informed that the researcher is investigating the behaviour of the students in the learning episode and assessing their opinion on the impact of the learning methodology.
6. The Setting/Context: The participants will be informed that all project investigations will take place in Tallaght Community School. All research will be conducted after school in the after school STEM Club.
7. A copy of the final project report will be made available to the participants if they would like to request a copy.
8. The research investigation will only commence when the researcher has been given permission from both the parents and all the students involved.
9. The project will only commence when the researcher has received permission from the Board of Management and the Principal of Tallaght Community School.

<u>Ethical Issue Number 2: Will your project involve photographing participants or electronic audio or video?</u>

Yes, this research investigation will require the use of electronic audio to record the responses from the participants who participate in the focus group discussion. The interview will be transcribed immediately after the interview and the audio will be deleted after the approval of the dissertation by the relevant examination board.
The data that is collected from the participant's in the project will be stored on two USB sticks. These devices will be stored in the school safe throughout the duration of the project. All data

saved on the password will be encrypted to insure the protection of any information stored on the USB cannot be understood by anyone else other than the researcher. No names or any information revealing personal nature of the participants will be recorded on the USB Stick. The file names on the device will not contain any information regarding the participants.
Participants will be given the opportunity to review the transcripts of the focus group. Participants will have the opportunity to retract any statements they have made.
Participants will be offered the opportunity to refuse to participate in the in the project at all stages. In the focus group participants will be offered the opportunity to refuse to answer any questions if they wish to do so. Participants will be informed at the start of the focus group that their responses will be used as part of research conducted in this project.
If at any stage the participant demonstrates any signs of distress or discomfort the participants need to be made aware that they can leave the project or the focus group.
All details on the USB stick will be deleted once the research project is submitted.

Cite any relevant legislation relevant to the project with the method of compliance e.g. Data Protection Act etc

- Data Protection Acts 1988 and 2003: The researcher will adhere to protocols and regulations in this act. For research conducted as part of the MSc in Trinity College Dublin, it is recommended that all information regarding the research project be retained for 10 years after which all information will be destroyed as appropriate.

- Teaching Council Code of Conduct and National Vetting Bureau, Children's and Person's Act 2012: The researcher is a fully vetted teacher with teaching council registration. The researcher will adhere to all policies and practices outlined by the teaching council.

Appendices 10: Sample Permission Forms

Student Letter, Information Sheet, Consent Form

Letter to Student's

Dear Students, November 2016

My Name is Ian Boran, I am currently a practicing teacher in Tallaght Community School and I am currently in my final year of my Masters in Technology and Learning (MSc) in Trinity College Dublin. As part of my final year dissertation I am conducting a research project on the topic of computational thinking and technology in the classroom. My research title is titled "**As part of a 21st century learning activity an Investigation into the effect of applying computational strategies when using bridge simulation technology on enhancing problem solving skills in Maths Education."**

I would be extremely grateful if you gave me permission for you to participate in this research project. Please find attached a copy of the student information sheet and consent form outlining information regarding the research project.

Please note you are under no obligation to participate in this study and may withdraw from the study at any time. Should you decide to withdraw from the study they can still participate in the STEM Club and will participate in the same learning activities.

Should you have any questions or require any clarifications about the study please do not hesitate to contact me or my supervisor.

Finally, I would like to thank you for taking the time to consider this request.

Regards,

____

Ian Boran
Email: borani@tcd.ie
Tel: 0851109940

Supervisor: Brendan Tangney
Email: tangey@tcd.ie
Tel: 01 8961765

Information Sheet for Students:

Title: **"**As part of a 21^{st} century learning activity an Investigation into the effect of applying computational strategies when using bridge simulation technology on enhancing problem solving skills in Maths Education".

Study/Rationale**:** I am currently in my final year of my Masters in Technology and Learning (MSc) in Trinity College Dublin. As part of my final year dissertation I am conducting a research project on the topic of computational thinking and technology in the classroom.
The aim of this research project is to investigate the use of computational thinking skills with the use of Bridge design software on developing problem solving skills. Problem solving is a key skill that is required in the new Project Maths curriculum. The learning activities are designed to improve your overall problem solving abilities.

The following information will provide an insight into the participation requirements involved in the study.

- The project will take place in the after school STEM Club. The project will take place twice a week for 1 hour over a 4-week period.
- No work will be assigned to participants outside of this timeframe.
- If you agree to participate in this study, you will be required to participate in the following data collection methods:
- A pre and post-test will be conducted to access your problem solving abilities.
- A pre and post questionnaire will be given to understand your thoughts on problem solving.
- You may be asked to participate in a focus group interview to share your thoughts on the learning experience.
- The researcher will record observational data on the behavior of your interaction in the learning activity.

The learning Activities*:*
In the learning activities students will work on a series of computational strategies to help them solve a series of bridge design problems using a Bridge design software. Students will be asked to work in groups to solve the problems presented to them. Students will be briefed at the start of each learning activity on the purpose and content involved in the learning activity.

Voluntary nature
Participating in this project is voluntary. You may change your mind and stop at any time. You may also choose to not answer a question for any reason.

Benefits
I hope that this project will result in the improvement your computational and problem solving skills and develop skills that are useful for the 21^{st} century.

Risks and Discomforts:
Answering questions about one's experiences may be uncomfortable. You can choose not to answer a question at any time. You may withdraw from the study at any time without penalty. You may withdraw your permission of participation at any time.

Confidentiality
I plan to publish the results of this study. My report will not include any information that would identify you or the school. To keep this information safe, I will delete the audio file after it has been transcribed. The transcript will be stored on an encrypted and password-protected USB device. This USB device will be stored in the school safe for the duration

of the learning experience No student will be able to be identified from the transcript of the interview. All other information will be stored in the school safe throughout the learning experience. I cannot absolutely guarantee confidentiality because the students will share information in front of each other during the interview. I will address this by asking that students not repeat what others said. After the approval of my dissertation by the relevant examination board all information will be deleted.

Conflict of interest Statement:

As the researcher also teaches you, he is aware that there may be a conflict of interest in this investigation. To address this. I guarantee that I will observe good ethical conduct throughout the research investigation. I foresee no risks associated with you participating in this. Should you have any questions or require any clarifications about the study please do not hesitate to contact me or my supervisor.

Regards,

____

Ian Boran
Email: borani@tcd.ie
Tel: 0851109940

Supervisor: Brendan Tangney
Email: tangey@tcd.ie
Tel:

Student Assent Form: Dissertation Research Project.

Lead Researcher: Ian Boran

Title: "As part of a 21st century learning activity an Investigation into the effect of applying computational strategies when using bridge simulation technology on enhancing problem solving skills in Maths Education".

Background Research:
This research will investigate the merits of incorporating computational thinking strategies with bridge design technology in a 21st century learning environment to develop problem solving skills. With the introduction of the new Junior Cycle in 2011 and the new Project Maths curriculum in Ireland there is a change in emphasis on the skills required for students in Maths and in school today.

Procedures of this Study:
This research investigation will include eight one hour sessions over a four-week period in an after school STEM club in a secondary school in Dublin. The learning activities designed in these workshops will be constructed to develop computational thinking and problem solving strategies. Students will be asked to participate in the data collection which will involve a pre and post-test on problem solving abilities, a questionnaire on attitudes towards problem solving, participation in a focus group interview to discuss the participant's opinions on the learning intervention and allow for the researcher to collect observational data on the participants in the learning activities. No recordings will be replayed in any public forum or made available to any audience other than the current researcher.

Publication:
This dissertation will be published as a part of my MSc in technology and Learning. I promise not to include any information that may identify the participants or the school in this research project. To keep the information safe all data will be stored on an encrypted USB stick which will be password protected. The USB will be stored in the school safe throughout the learning experience. No names of any participants will be used in the transcript of the audio interview. I cannot absolutely guarantee confidentiality because the students will share information in front of each other during the interview. I will address this by asking that students not repeat what others said. Individual results may be aggregated anonymously and research reported on aggregate results.

DECLARATION:

- I am under 18 years old and I am not competent to provide consent. Permission has been sought from my parent/guardian to participate in this study.
- I have read, or had read to me, an information form providing information about this research (as detailed above) and this consent form.
- I understand that my participation is fully anonymous and that no personal details about me will be recorded.
- I understand that it is a teacher of Tallaght Community School is running this study but that no information in this study will be used to identify me.
- I have had the opportunity to ask questions and all my questions have been answered to my satisfaction. I understand the description of the research that is being provided to me.
- I agree to my data being presented as part of the project work for the MSc in Technology and Learning in a way that does not reveal my identity.

- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I agree to being observed, by the researcher in the learning experience.
- I understand that in the unlikely event that illicit activities become known over the course of this research, these will be reported to appropriate authorities.
- I agree to being interviewed by the researcher in the school after the intervention. I understand this interview will be recorded (audio only) and once transcribed, the audio recording will be deleted.
- I understand that I may refuse to answer any question (in interview or questionnaires) and that I may withdraw at any time without penalty.
- I understand that my data will be stored securely and deleted after the approval of my dissertation by the relevant examination board.
- I have received a copy of this agreement.

I ______________________________consent to taking part in this research project.

Signature of Participant: ___________________________ Date: ___________

Signature of Researcher: __________________________ Date: ____________

Statement of investigators responsibility:
I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent. I undertake to act in accordance with the information supplied

RESEARCHER CONTACT DETAILS: borani@tcd.ie

Appendices 11: Sample of coded focus group transcript.

Post Interview transcripts:

How did you find the project, did you like it?

B3, C3, O3

X: Yeah it thought it was quite fun, it was enjoyable to be able to learn this way, rather than learning the normal way it was more fun to learn using the technology and the software. Like the bridge, design software was cool and, the classes flew by, we didn't realise that we were working so hard. C3 C3 D3 D3

Y: Yeah it was good, it was good to get away from the normal stuff in class, instead of just doing maths, getting a break from the normal classes in maths.

C3, O3,

Z: yeah its something different, and to be honest the good thing was that we didn't even feel that we were doing maths.

Do you think your problem solving skills were affected/developed at all:

X: Yeah I think that my problem solving skills were increased a little bit, B3

Like sir, I think because we have learned maths from different teachers for the past 10 years or so, we all have different levels of ability and interest in maths. So if we had of done the project when we were in 1st year it would have helped us more, because our brains are kind of programmed to answer in a certain way. B3 *

B3

Yeah sir why do we learn fractions and decimals in first year, if we learned this then we could use this to help us when problem solving. Do you know the worded questions at the end of each chapter, there all problem solving so, I always find them difficult, but If we were better problem solvers then it would be a lot easier, B4 B4

B3

Yeah I think my problem solving skills got a little bit better, the model helped me to get my head thinking about the problem instead of jumping straight into the problem and then getting frustrated. A3 A4

A3

Yeah the problem solving model helped a lot, especially in the more difficult problems, where we didn't know what to do, it helped me really structure what the problem was looking for and how to check to see if the solution was correct. A3 A4

Like the steps helped us on how to problem solve, and gave you hints, for like what to do next and how to do it. Yeah like when you finished working out problem, like the simulation was so good to help to check to see if your solution worked, because that's the frustrating thing with the worded questions, sometimes you are not sure if your question is right, and even if you got the problem wrong, you could work out the solution by analysing and looking at the parts of the bridge that could be fixed. A3 C3 A3, C3

A3 C3

You start to learn by looking back at your mistakes and then you can change your design or fix the bridge. See what worked and what didn't and then you can see what went wrong. A3, C3

What did you think about working together in teams?

R: I am more of an individual worker, I like working it out for myself, I like to do it yourself person. I am the same I don't like working in groups, I prefer working on my own.

D4 D4

Appendices 12: Sample of coded field notes.

Ch
Bh peşlu

Some students again are getting frustrated, "This is annoying, it's not working when I move this bar"

It's just not working, we know what we have to do, but it wont let us.

Teacher: You don't want it to small or it will cave in

Student we will worry about the cost later, lets just get the bridge stable first and then , A2

Good example of higher order thinking A2

Student: Sir does it make a difference is the truck goes faster or slower over the bridge? A2

Student Quote: "this is fun sir, it's better using laptops, and it's fun and enjoyable and you concentrate more because you are doing it yourself" D3, A3, C3

Session 4: Friday 10/02/2017

D3 B3. A2

All groups are now on the difficult problem solving questions; the level of communication in each group has increased. The majority of the groups are now comfortable in using the technology and are demonstrating high levels of creativity with the solutions to the problems. Students seem to be really enjoying the learning experience, with students, laughing and expressing their satisfaction when there solution works. B3, B3

C3

Good questioning and conversations between the groups is occurring A2

"How do we make this member less wobbly and we need to get these members to be more blue and red in colour to maximise efficiency for tension and compression forces" A2

Student's levels of engagement are great, students and shouting "Yes" aloud when they get the bridge to pass over the bridge. D4, C3, B3.

A3

Students are definitely developing confidence in using the problem-solving model, the levels of planning that the students are doing and the conversations that are taking place involve the all of the planning, testing and reflecting steps inherent to the problem-solving model. A3

A2
D3
A3
B3

With the more difficult problems students are having to work together to work out potential solutions, and it is evident that the students are using the problem-solving model to help the plan how they are going to fix the bridge

Again, the groups that are working well, the group dynamic is good, each student feels comfortable to share express and try new ideas with each other. In the groups that could work better, I think the group dynamic is a factor. Some students are more quiet and don't seem to offer their opinions to the group.

D3 A2, B3 Neg Bh

Sesssion 6:

A3
A2

Students are now working on the open-ended problem solving questions. Students are using the problem-solving model to help them plan and prepare their presentation of their ideas. Students seem to enjoy the fact that they get the opportunity to present their ideas and are trying hard to make their bridge design original and unique.

D3, B3 A2

Appendices 13: Frequency of Table of coded data.

	post	obs	pre	stuck	prethink + retell
A1	0	0	7	3	0
X1	0	0	16	4	0
A2	23	26	0	3	40
X2	0	0	0	0	2
A3	31	12	0	1	5
A4	42	0	0	0	0
B1	0	0	3	1	0
B2	0	0	19	3	0
B3	29	14	0	0	20
B4	9	frustration 3	0	1	4
C1	0	0	8	0	0
C2	0	0	3	0	0
C3	36	10	0	9	6
C4	1	3	0	1	0
D1	0	0	10	0	0
D2	0	0	5	0	0
D3	25	17	0	4	14
D4	9	4	0	0	4

Appendices 14: Table of Excel Data for MCAI Questionnaire

Name	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13	Q 14	Q 15	Q 16	Q 17	Q 18	Q 19	Q 20	Q 21	Q 22	Q 23	Q 24	Q 25	Q 26	Q 27	Total (135)	Percentage
A	5	4	5	3	2	4	4	5	2	4	3	4	5	4	5	5	5	3	5	3	4	5	1	5	2	2	5	104	77
B	3	3	4	3	4	4	3	4	4	5	2	3	3	3	5	4	3	3	3	4	3	4	1	3	4	3	3	91	67
C	5	4	4	4	3	5	4	4	5	3	2	4	4	3	4	4	3	3	3	5	3	4	2	2	1	5	4	97	72
D	4	4	4	4	3	3	4	3	3	4	2	3	4	3	3	2	3	3	3	3	3	2	2	3	2	3	3	83	61
E	3	3	4	3	3	2	3	4	3	2	1	3	1	2	4	2	3	3	4	2	3	5	4	3	2	3	3	78	58
F	5	4	4	4	4	5	5	4	4	3	2	4	2	2	2	3	4	4	3	3	4	2	2	2	2	1	1	85	85
G	3	3	2		2	3	3	4	3	3	3	3	3	2	4	2	3	2	3	4	3	3	2	3	2	3	3	74	57
H	5	4	5	4	3	3	3	5	5	4	5	4	3	3	4	3	4	3	3	3	3	4	2	5	3	5	4	102	76
I	4	5	3	3	3	4	2	4	4	5	2	3	5	2	4	3	5	5	4	5	3	3	2	4	2	5	4	98	73
J	4	3	3	3	3	2	4	2	2	2	2	3	2	2	3	3	3	2	3	3	2	1	2	2	2	2	2	67	50
K	3	4	2	1	2	3	4	3	2	2	4	5	3	2	4	2	3	4	3	4	5	3	2	4	5	3	3	85	63
L	5	4	5	5	4	4	4	5	4	4	5	3	5	3	5	5	5	5	4	4	3	3	4	2	2	2	2	106	79
M	4	3	4	4	3	3	4	4	4	4	1	5	4	4	4	4	4	4	4	3	2	1	1	2	1	3	5	89	66
N	5	3	4	4	4	3	2	4	4	5	2	2	4	3	5	4	4	4	5	3	4	5	3	4	4	1	4	99	74
O	3	1	3	2	3	2	3	3	4	3	3	3	3	3	2	1	3	3	3	5	3	3	2	5	2	5	1	77	57
P	3	3	3	3	3	3	2	3	4	3	2	3	2	2	3	1	3	2	3	3	3	3	3	3	2	2	3	73	54
Q	4	4	5	3	4	5	3	5	4	4	3	3	4	3	5	3	3	4	5	5	4	2	1	1	1	2	2	92	68
R	2	3	4	2	3	2	2	4	1	3	3	3	4	3	3	2	4	5	3	2	3	2	4	3	4	2	2	78	58
S	5	3	5	5	5	3	3	3	5	5	2	5	3	3	3	5	5	3	3	3	3	3	1	3	3	3	5	98	73
T	5	3	5	5	3	3	3	5	2	2	1	2	3	4	3	3	3	3	5	3	3	5	5	3	1	2	3	88	65
U	4	3	4	5	3	3	4	2	3	4	2	2	2	2	2	1	3	2	5	3	3	5	2	5	4	5	3	86	64
Mean																												88.095238	66.52381

Appendices 15: Sample Focus Group Transcript

Post interview Focus Group 2:

T: What were your thoughts on the learning activity?

X: yeah it was good, I learned a lot about bridges,

Y: you don't have to use expensive metals to build a stable bridge,

Y: yeah It was good sir, like I don't normally get involved in maths classes because I don't like maths but I found this project really interesting. Like I don't normally like maths but, this was something different,

Z: It was fun and the time flew by in classes, ye didn't even realise that you were doing maths half the time, which was good. Like I found that maths easy for a change… like I never thought I'd be interested in looking at the physics in the bridge design…

T: Why?

Z: Physics is all this mad stuff, and I wouldn't know what to do, but using the technology and the problems were good way of learning about how to build a bridge.

X:Yeah like the maths we doing was hard, like analysing all the data and looking to see where the bridge was unstable, and looking for patterns but we didn't realise that we were actually working that hard.

H: No like I didn't think id ever be able to build bridges or design them, but the project was really good because when you got the bridge to work it the truck passed over the bridge it felt great that we got it to work.

J:Yeah im the same, especially with the difficult bridges, like we were all excited to check to see if our design worked.

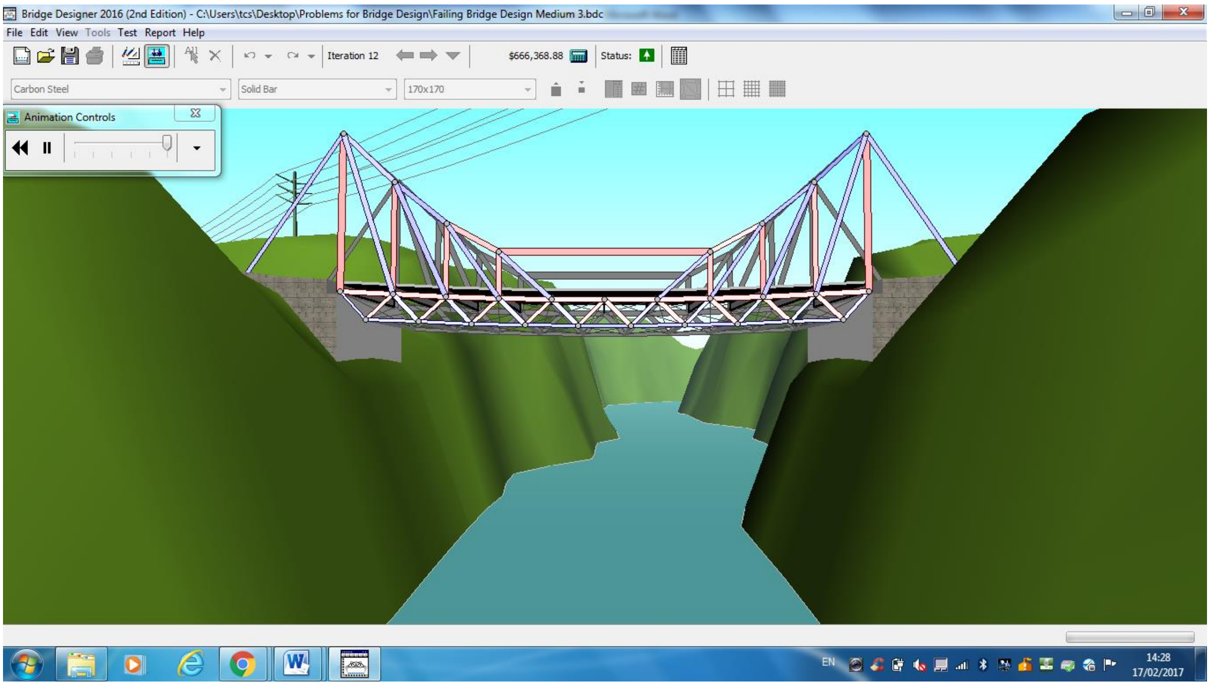
Y: Yeah I agree with x, the project was fun, and it's better than writing all the time doing it on the

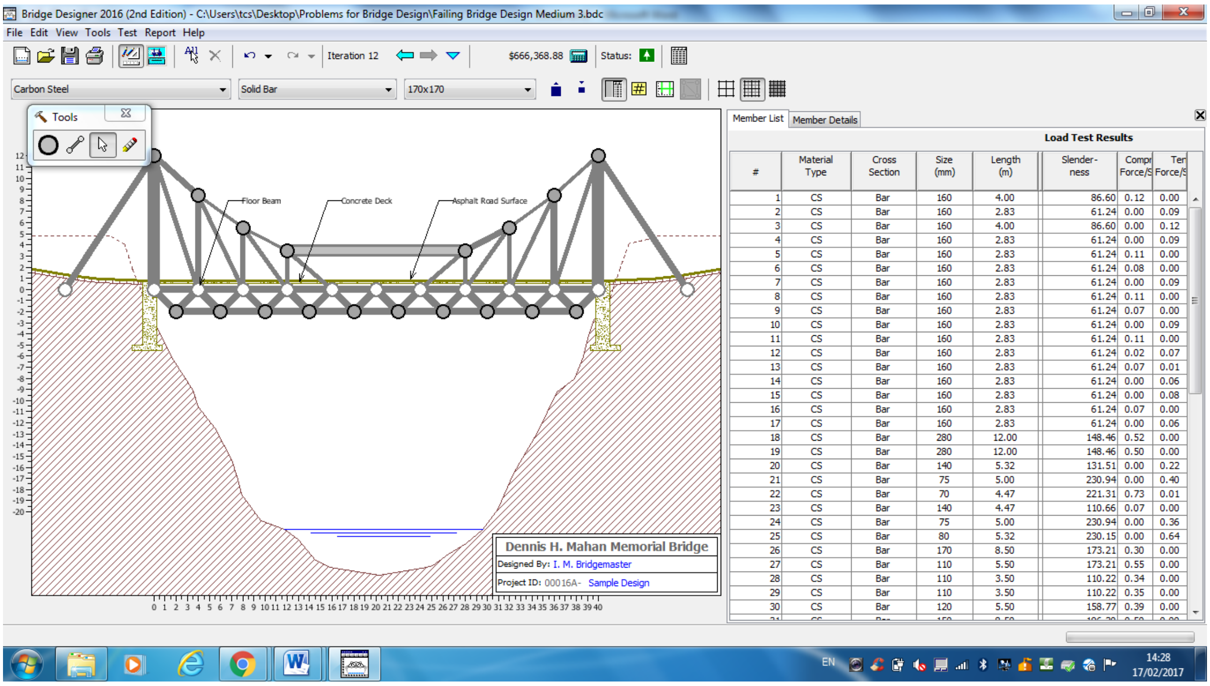
Appendices 16: Sample of Participants Artefacts

Medium 3

Our goal is to review the safety of the bridge and make sure the suspension is acceptable.

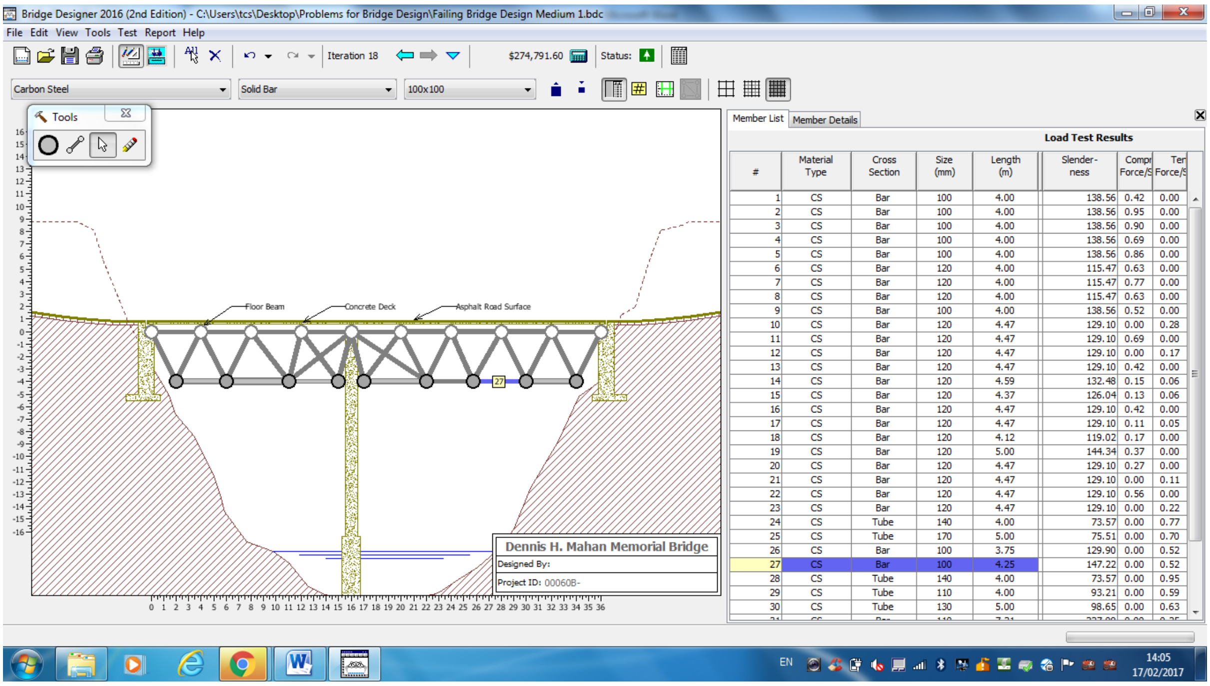
We added bars to the missing parts underneath and decreased and increased the size of some of the bars, we separted bars using a hollow tubes

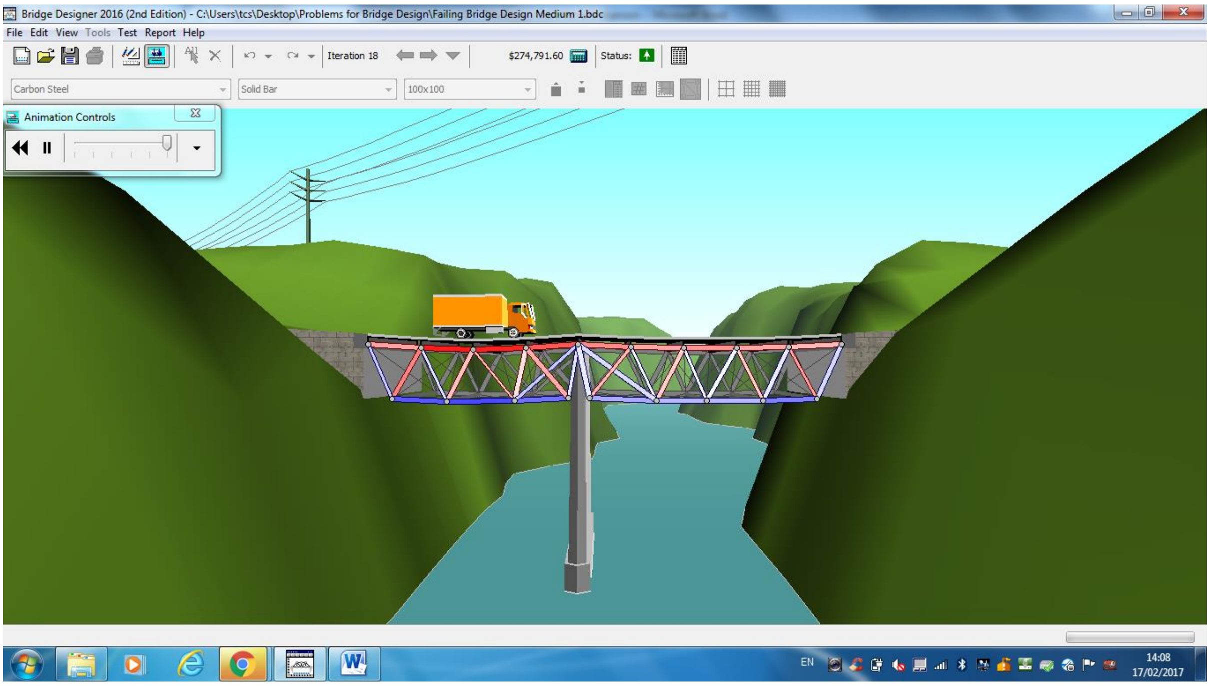


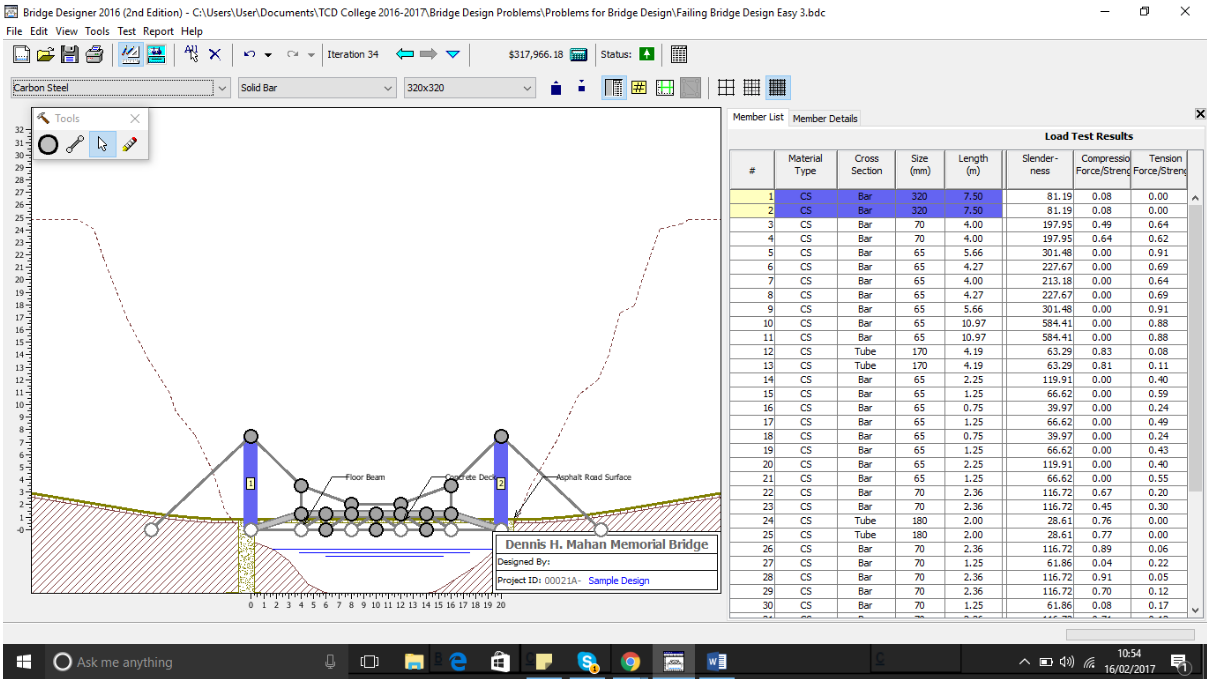


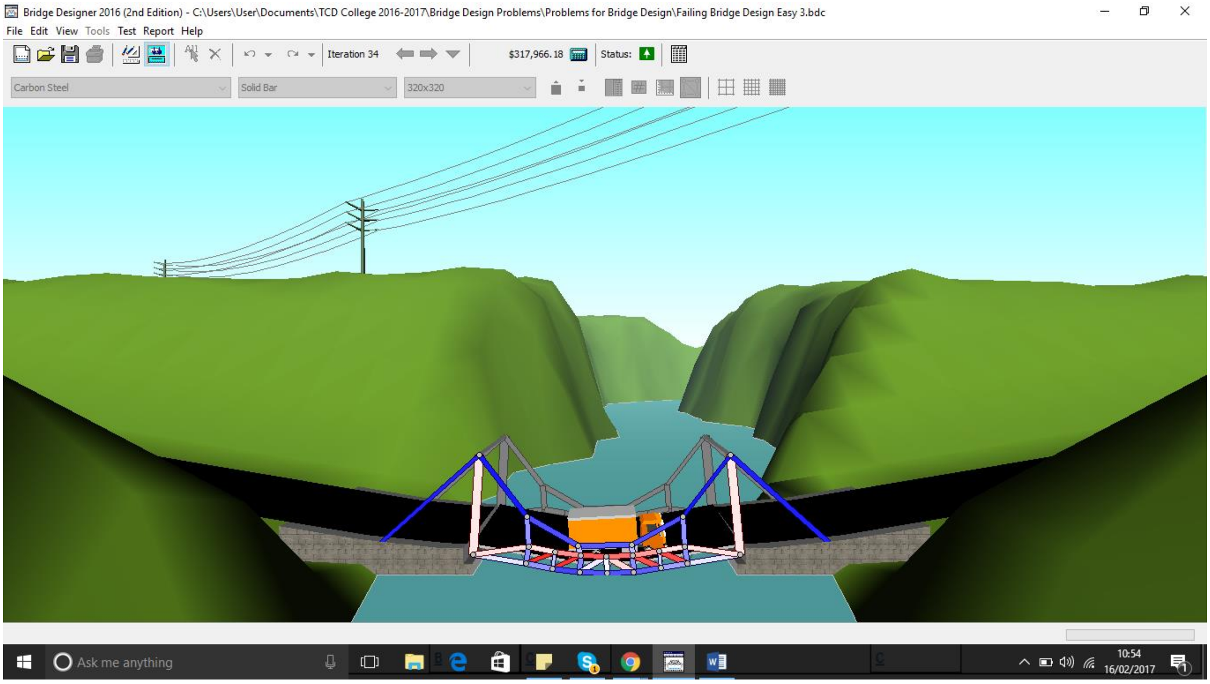
Medium 1

We reviewed the bridge design and discovered its faults, the supports underneath were not efficient and would not support the own weight of the bridge and the truck altogether. We decreased the price of the bridge altogether to less than 300,000£ and made it efficient for the truck to pass over the bridge.



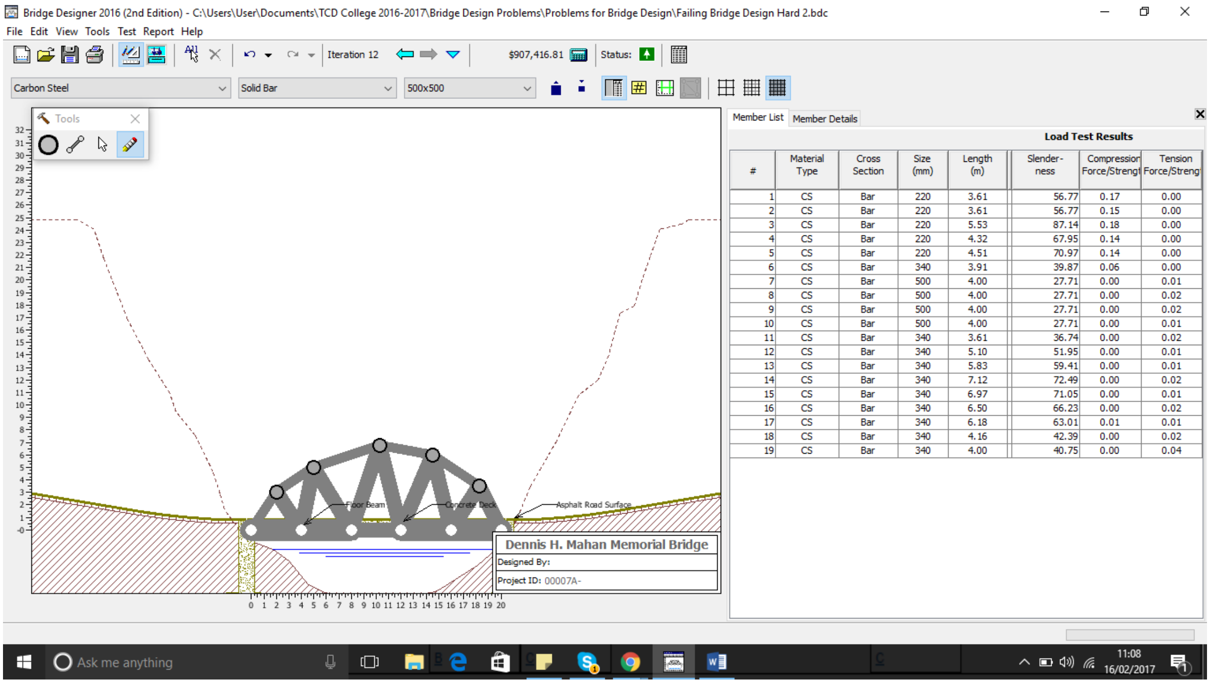


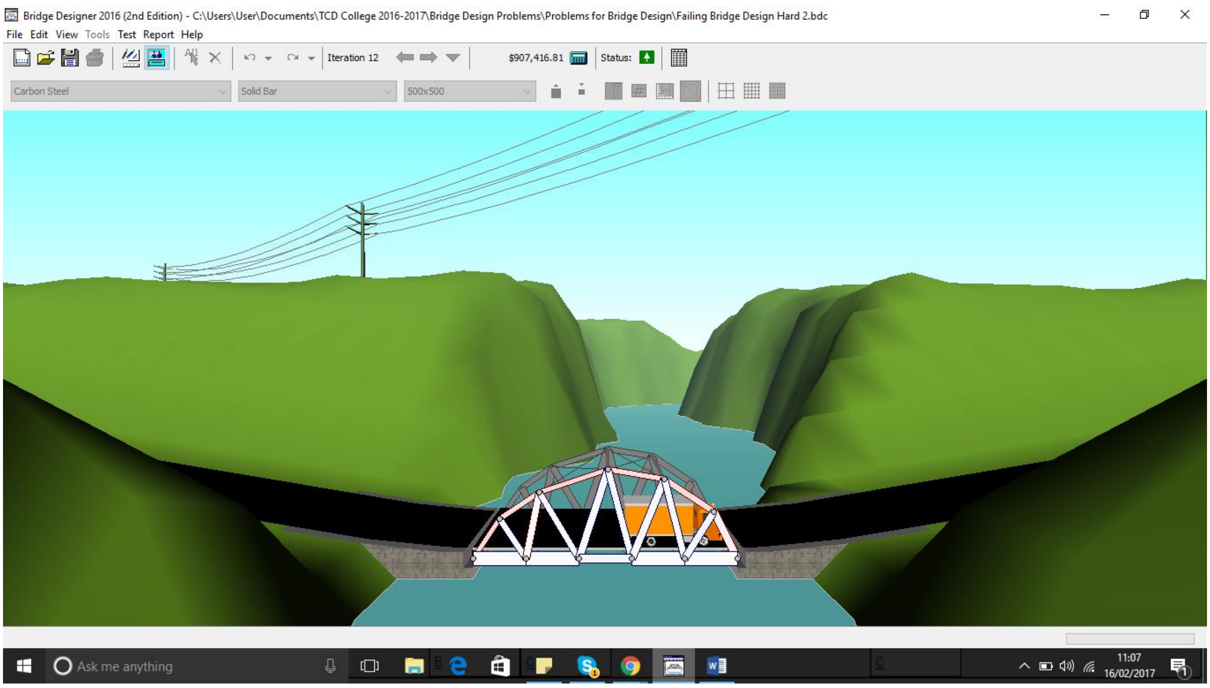




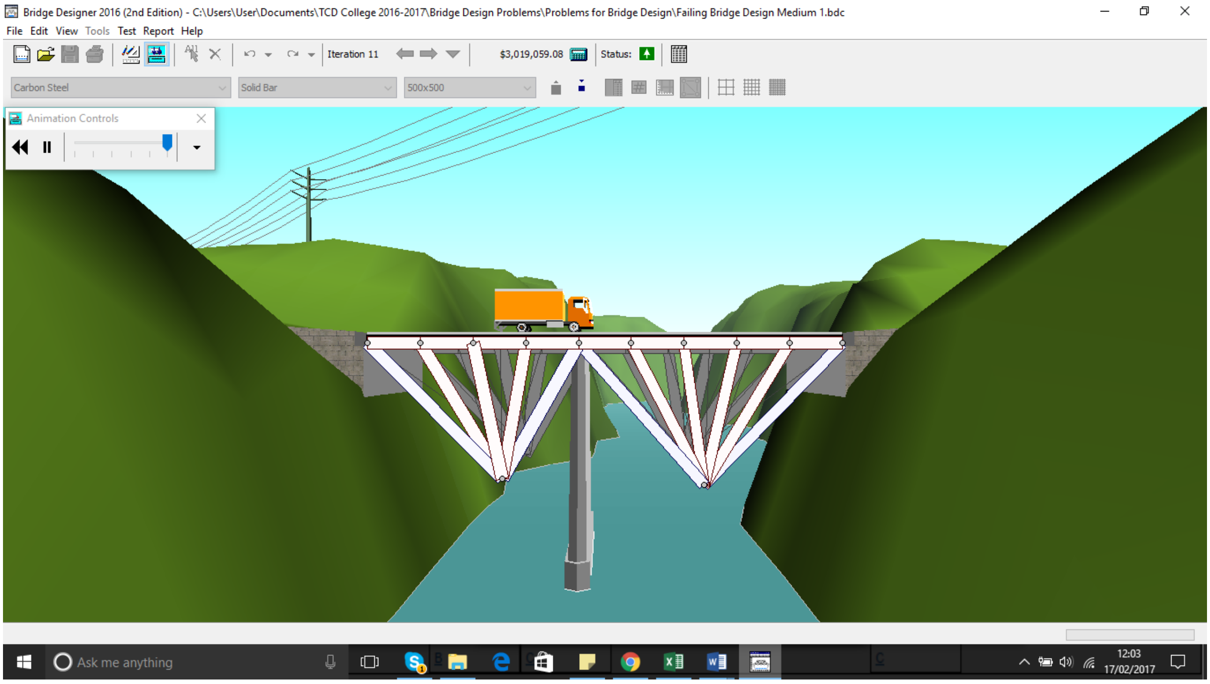
We figured out what was making the bridge collapsed and it was that the two main bars were not strong enough to hold up the weight of the bridge. We solved this problem by making the bars stronger and changing their size.

Easy 3





Medium 1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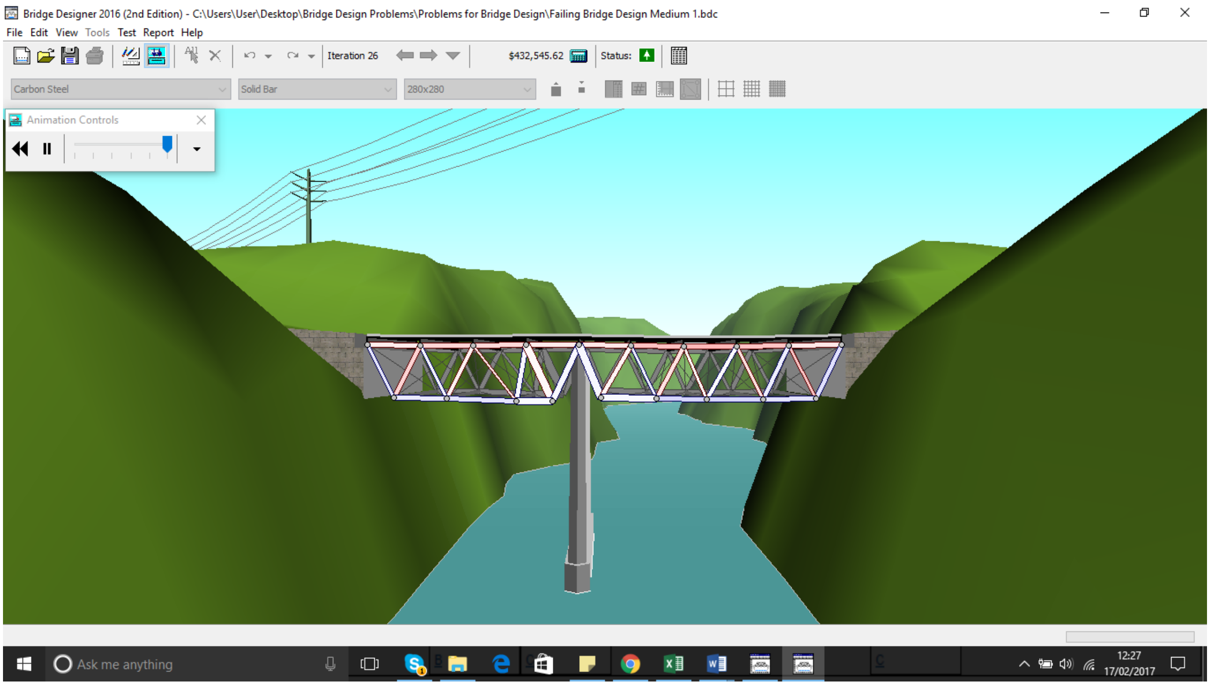
Medium 2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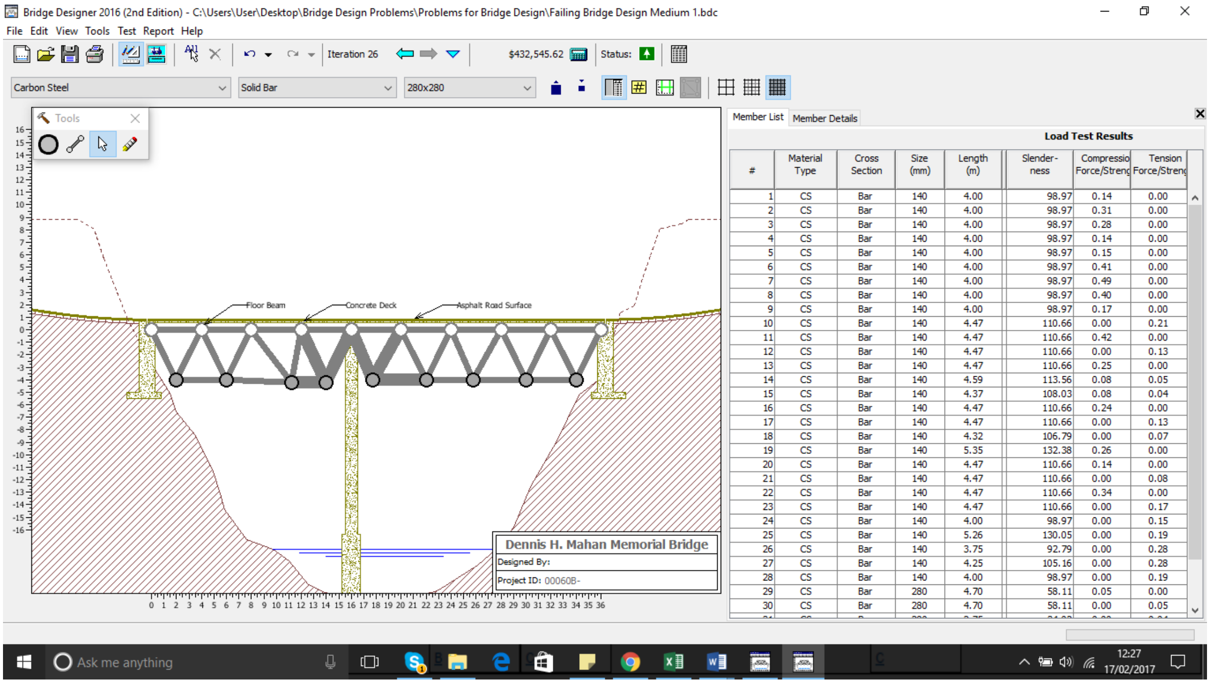

We used to problem solving bubble to solve what was wrong and then we moved up bars to keep it reinforced and capable of holding the bridge we also extended the bars and thickened the bars to 230x230.