Investigation into the use of microworlds as part of a 21st century learning activity and the impact on student engagement and confidence in physics.

A dissertation submitted to the University of Dublin, in partial fulfilment of the requirements for the degree of Master of Science in Technology & Learning

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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.

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Abstract

The declining number of students considering a career in science related disciplines has often been linked to didactic teaching styles in classrooms, with an emphasis on transference of knowledge from the teacher to student and where text books are the main source of curriculum content. In physics, teaching is often focused on the application of mathematical formulae and lacks context for the student to apply to real world problems. Many students find physics a ‘difficult and hard subject to study’ leading to poor motivation and low engagement with the subject.

One approach to address these challenges is to consider the use of appropriate technology combined with a more suitable, student centred, pedagogical model. The affordances of microworld simulations to impact student engagement and motivation have been the subject of much research. These technologies can be highly immersive, incorporating interactive, construction features and have the potential to redefine a student’s learning experience. However these technologies do not sit well in conventional classroom settings, where short class durations, didactic pedagogy and an emphasis on teaching to the curriculum prevail. An alternate pedagogical framework is needed. Research points to the benefit of a social constructivist, collaboration enabled pedagogy to impact conceptual understanding in physics. When learning is also contextualised, students can apply domain specific knowledge to real world problem solving situations.

This dissertation brings three key elements together –microworld technology, a social constructivist contextualised pedagogy and a 21st century learning model – to investigate the impact on student engagement and confidence in physics. An exploratory case study was carried out as part of the Bridge21 programme, an alternate 21st century learning framework that emphasises collaborative, problem based activities. A total of 39 secondary school students participated in 4 separate physics workshops, with students working in teams and using microworld simulations on dedicated workstations. The PhET Circuit Construction Kit microworld, developed at the University of Colorado, Boulder was used in each workshop.

A convergent, parallel, mixed methods case study methodology was used for this investigation. A validated attitudinal questionnaire (MTAS –Mathematics and Technology Attitude Survey) was adapted for quantitative data capture, while focus groups and observation provided rich qualitative data for triangulation. The findings from the data show statistically significant changes in student engagement, confidence in physics and an improvement in attitude to the use of technology for learning. The qualitative data provides context for these findings and through congruence with the quantitative data supports the conclusions reached from this case study investigation. The limitations of this small sample case study are also discussed and additional areas for future research suggested.

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Chapter 1: Introduction

1.1 Motivation for the Research

There has been a much reported decline in the number of secondary level students studying physics (McBride, Zollman, & Rebello, 2010b; Oon & Subramaniam, 2011). Students find physics boring and perceive it as not relevant to their lives and experiences. Students believe that it is a hard subject, requiring strong mathematical ability. For these reasons Biology and Chemistry are more popular subjects for students to choose. Despite differing educational contexts, research from several countries (Lyons, 2006) is consistent and points to 3 key reasons for these perceptions of physics.

1) **Transmissive Teaching styles**. In many classrooms the teaching of physics is centred on the transference of knowledge from the teacher to the student. Students are asked to listen, record information from whiteboards and use text books as the primary method of accessing the required curriculum. This teaching style limits opportunities for discussion and for encouraging students' own interpretation of the theory. A consequence of this is that learners believe physics is about known facts, where one is either right or wrong. From and Irish context such transmissive pedagogies are maintained due to the requirement to teach for success in high stakes state examinations.

2) **Lack of Relevance.** A common theme from the research is students believe that physics is abstract and is not relevant to their everyday lives. This leads to the perception of it as boring. Physics is often taught first from the statement of the theory and then using mathematical formulae to prove it. There is limited opportunity for students to incorporate their experiences into the subject.

3) **Physics is Difficult.** Common across many national education contexts, physics is considered a hard subject with a requirement for good mathematical capability. Attitudes to difficulty often stem from the way the subject is taught (transmissive pedagogy) and to its relevance to everyday situations. Of the 3 science subjects biology is considered the least difficult, followed by chemistry.

As well as a decline in the numbers studying physics there are implications for students that do select it. The research points to low levels of engagement among students and poor conceptual understanding of the core concepts in physics (Flavio S. Azevedo, 2006; Baser, 2006; Saleh, 2011). Several models have been proposed to define engagement (Connell & Wellborn, 1991; Eccles & Wigfield, 2002; Skinner & Belmont, 1993) and can be summarised as follows:

Emotional Engagement: this relates to the students levels of boredom, sadness, happiness and how they view the importance of the task.

Behavioural & Cognitive Engagement: this examines a student's level of concentration, involvement in activity and a student's willingness to take on new challenges. Students will persevere with problem solving and learn from mistakes.

A central part of this research study is concerned with ways to improve emotional and behavioural engagement in physics.

1.2 Pedagogical Approaches

The problems with transmissive teaching methods in physics suggest that an alternative pedagogical approach needs to be examined. Research by Handelsman et al (2005) has shown that a student centred approach, which encourages active learning and collaboration can lead to improved engagement. Student motivation increases when learners are given the opportunity to discuss and reflect on their learning.

Constructionism is an approach to learning that requires the creation of an artefact during the learning activity which can be subsequently shared with others (Harel & Papert, 1991; Papert, 1980, 1984). This helps build the framework onto which subsequent knowledge can be added. Papert (1984) proposes that constructionist activity develops the internal understanding of what is outside and then the externalisation of what is inside the learner. This cognitive constructionist model provides a potential framework for addressing cognitive and behavioural engagement in physics.

Contextualised learning relates learning to real world examples that are relevant to a diverse range of students (S. Glynn & Koballa, 2005; S. M. Glynn & Winter, 2004). When students can make connections with situations in their own lives they are more motivated to learn (Bennett, Lubben, & Hogarth, 2007).

Constructivism considers learning as a shared or social activity in which learners add to and build on each other's knowledge (Piaget, Brown, & Thampy, 1985; Vygotskiĭ & Cole, 1978). Learning is more effective when learners collaborate than by learning on their own. Piaget believes that introducing cognitive conflict (or dissonance) will challenge the learner to consider alternate models and improve cognitive engagement and conceptual understanding.

1.3 Technology Potential

Recent literature has highlighted the potential of simulations and microworlds to support student engagement and conceptual understanding. Simulations usually provide a representation of physical phenomena, with varying levels of interactivity which allow the user modify, create or alter parameters that will generate a response within the simulation. Simulations also allow multi representations of phenomena which has been shown to have a high educational impact (Martínez, Naranjo, Pérez, Suero, & Pardo, 2011; van der Meij & de Jong, 2006). Software development has resulted in increasing levels of sophistication within simulations, allowing representation of abstract concepts as well as the more accurate modelling of the physical phenomenon (Hilton & Honey, 2011).

Several research studies have examined the affordances of simulations to develop deeper conceptual understanding (Dori & Belcher, 2005; Perkins, Moore, Podolefsky, Lancaster, & Denison, 2012; Treagust, Chittleborough, & Mamiala, 2002; Z. Zacharia & Anderson, 2003). Martinez et al (2011) have investigated the impact of such *'hyper-realistic virtual simulations'* and found a statistically significant improvement in concept assimilation.

The ability of simulations to benefit a learners understanding through visualisation has been demonstrated in science subjects (Blikstein, Fuhrmann, Greene, & Salehi, 2012; Jennifer L. Chiu, DeJaegher, & Chao, 2015; ND Finkelstein et al., 2005). Chiu et al (2014) has demonstrated improved conceptual understanding of chemical reactions through the use of dynamic molecular visualization simulations.

Girvan et al (2013) have examined the educational benefits of constructionist learning in virtual worlds. The concept of low floor (easy to use), high ceiling (advanced capabilities) and wide walled (range of construction features) is proposed as an important requirement in the design of constructionist tools for learning.

Microworlds have been likened to playpens or sandboxes, providing the learner an opportunity for 'creative exploration' (Ackermann & Strohecker, 1999). There can often be blurring of the lines between the capabilities of simulations and microworlds. A definition of a microworld that is helpful for the purposes of this investigation is given by Rieber (2005)

> *'Microworld: An interactive, exploratory learning environment of a small subset of a domain that is immediately understandable by a user and also intrinsically motivating to the user. A microworld can be changed and modified by the user in order to explore the domain and to test hypotheses about the domain.'*

Dual coding theory (Paivio, 2013; Sadoski & Paivio, 2012) is a useful framework from which to understand the role simulations and microworlds can play in cognition and learning. Microworlds have the potential to build stronger referential links between concepts learned verbally and those experienced through visualisations and interactions within the microworld.

1.4 21st Century Learning Model

Traditional classroom environments, with didactic teaching style and short class durations are not ideal environments in which to implement learning through technology (B. Tangney, Bray, A., & Oldham, E., 2015). Several 21st century learning models have been proposed (Dede, 2010; J. Voogt, Erstad, Dede, & Mishra, 2013; Joke Voogt & Roblin, 2012) and they share many common characteristics. They emphasise critical thinking skills, collaboration, contextualised learning and problem based activities. Guided discovery and a learner centred approach is prioritised over a teacher centred, tranmissive pedagogy.

ICT in education is often considered as a discrete subject area to be taught rather than how it may enhance student learning. From an Irish educational context McGarr (2009) has examined the historical investments and applications of ICT in schools. McGarr considers how ICT changes the structure of the classroom and instruction but also examines how existing pedagogy can change ICT. McGarr argues that schools assimilate technology rather than exploring the opportunity it presents to transform learning. This relationship between ICT and pedagogical model is an important consideration for the research discussed in this dissertation.

Bridge21, a specific implementation of a 21st century learning model has been shown to be an effective environment for technology mediated learning (Aibhín Bray, Oldham, & Tangney, 2013; Conneely, Murchan, Tangney, & Johnston, 2013; Johnston, Conneely, Murchan, & Tangney, 2014; B. Tangney & Bray, 2013).

In addressing shortcoming in mathematics teaching Tangney et al (B. Tangney, Bray, A., & Oldham, E., 2015) have investigated the combination of mobile technology with contextual and social constructive pedagogies with the Bridge21 learning environment. The initial results of this *'perfect storm'* (as referred to by the authors) is very positive and 'student engagement and appreciation of mathematics content are favourably affected'.

The design of this research study will follow a similar approach, but in this case the subject area is physics and will investigate the combination of microworld technology, a social constructivist contextualised pedagogy and the Bridge21 learning model.

1.5 Research Goal and Methodology

Considering the challenges and findings outlined in this chapter the purpose of this dissertation is to address the following research question.

- How do microworlds, when used as part of a 21st century learning model, impact student engagement and confidence in physics?

This gives rise to additional sub questions to be considered in this study

- Do microworlds impact students' attitudes to learning physics with technology?
- What factors need to be considered if microworlds are to be integrated into conventional classroom environments?

An exploratory case study involving 39 transition year (15-16 year old) students was used to address the research questions. Four day long workshops with 8-10 participants at each were held at Bridge21, a particular implementations of a 21st century learning model. A convergent parallel mixed method data collection was employed with pre and post MTAS questionnaires providing the quantitative data and the qualitative data generated through focus groups and observation. This dissertation presents the findings and conclusions of the case study. Considering the small sample size (n=39) potential limitations of the research are discussed and areas for further investigation proposed.

Chapter 2: Literature Review

2.1 Introduction

This chapter presents a review of the literature that informs and establishes the framework for this research study. The review addresses the challenges with current teaching practices and methodologies in science and in particular physics education. A model of student engagement is explored and factors that influence engagement in science learning are considered. Social constructive pedagogy and constructionist learning methods are also examined in the context of improving student engagement. Strategies for designing learning environments that create cognitive dissonance and improved conceptual understanding are presented. The affordances of technology, in particular microworlds, to support understanding of abstract concepts are examined. Bridge21, a 21st century learning framework, which incorporates collaboration, contextualisation, problem solving and technology in the learning activity, is considered. The literature review examines these three areas – pedagogical choice, technology and 21st century learning – and suggests how the can be brought together to impact student engagement and confidence in physics.

2.2 Challenges in Physics Education

There has been much research and discussion in countries around the world on the declining numbers of students studying science (McBride, Zollman, & Rebello, 2010a; Oon & Subramaniam, 2011; Shute, 2006; C. Williams, Stanisstreet, Spall, Boyes, & Dickson, 2003). Students perceive science subjects as difficult and abstract leading to low motivation and poor engagement. Instructional methodologies in most classrooms around the world follow a didactic and transmissive pedagogy with the teacher at the centre of the learning (Lindahl, 2003; Osborne & Collins, 2000; Osborne & Dillon, 2008). Teachers often cite pressures to complete the curriculum in short time frames and the requirement to prepare students for state examinations as reasons why this one way knowledge transfer between teacher and student persists (Lyons, 2006; Tobin, McRobbie, & Anderson, 1997). A consequence of this transmissive pedagogy is that students perceive physics as very structured and one in which you are either right or wrong. Learners are not afforded the possibility of alternate conceptions (Baser, 2006).

In physics education the focus is often on the memorization of facts, mathematical formula and understanding is achieved only through numerical problem solving (Osborne & Dillon, 2008). This style of teaching and classroom environment does not support students' deeper understanding of physics concepts. Tuminaro and Redish (2004) have shown that although students have the required mathematical knowledge they fail to apply this to physics environments. Research by de Souza, Barros and Elia (1997) suggest that physics teachers focus heavily on how to manipulate mathematical symbols and formulae and prioritise these over conceptual understanding.

In the UK in 2007, Physics was outside the top 10 most popular A level subject choice for students (Porter & Parvin, 2008). As students progress through secondary school their interest in physics declines at a much higher rate than other science subjects. Students perceive biology as interesting and physics as boring. C. Williams et al. (2003) conclude that a major factor as to whether a subject is considered interesting is based on its perceived 'relevance'.

2.3 Student Engagement

Motivating and keeping students engaged in science has been a persistent problem and particularly for higher grade students (Hidi & Harackiewicz, 2000; Lamborn, Newmann, & Wehlage, 1992; Newmann, 1992). Often students do not have an opportunity to contextualize learning of science concepts in real world scenarios and situational, problem based activities. Research in several countries has found that student engagement increased when the curriculum incorporated real world and contemporary examples (Lyons, 2006). Intrinsically motivated students will exhibit higher levels of engagement when teachers give them greater freedom and encourage self-direction in the learning activity (McCombs, 1991).

Classrooms with students seated in rows and where didactic instruction methods are adopted do not support active learning and engagement by students. Teaching methodologies are often anchored in rote learning with the acquisition of knowledge given priority and limited attention to developing metacognitive skills related to scientific literacy, critical thinking and problem solving. (Handelsman et al., 2005; W. M. Williams, Papierno, Makel, & Ceci, 2004)

Azevedo (2006) defines student engagement to mean 'the intensity and quality of participation in classroom activities'. This is evidenced by a student's ability to engage in ongoing discussion, contribute to the work and develop on other class contributor's inputs (Flavio S. Azevedo, 2006; Flávio S. Azevedo, diSessa, & Sherin, 2012; Engle & Conant, 2002). Others approaches have been proposed to defining student engagement and several theories break it into 3 main categories 1) behavioural, 2) cognitive and 3) emotional engagement.

Behavioural Engagement - considers a student's level of concentration, attention, persistence, involvement in group discussion and asking questions (Skinner & Belmont, 1993).

Cognitive Engagement - this level of engagement examines a student's willingness to take on a challenge and go beyond what is required. Students who have developed their problem solving skills, will work hard and learn from mistakes and manage setbacks (Connell & Wellborn, 1991). This level of engagement is important in science related disciplines like physics where problem solving ability and perseverance is required.

Emotional Engagement - this category considers a student's level of boredom, sadness, happiness and how they perceive the importance of the learning task for future goals (Eccles & Wigfield, 2002; Skinner & Belmont, 1993).

2.4 Conceptual Understanding

Conceptual understanding is an essential component in science learning (DiSessa, 2001; Forbus, 1997; Saleh, 2011; Z. C. Zacharia, 2007). However in many areas of physics such as electromagnetism and thermodynamics, there needs to be a strong link between conceptual knowledge and mathematical formulae for students to achieve success in physics problem solving tasks (Clark, Thompson, & Mountcastle, 2013). For many years research has suggested that conventional teaching methods are not best suited to encouraging students to investigate complex phenomena and to developing a deeper understanding of scientific concepts (Bransford, Brown, & Cocking, 1999). It has been proposed that learners gain a more complete understanding of physics concepts when experimentation, demonstrations and visualisations are incorporated into the instruction.

Conceptual understanding is difficult to instil in learners and requires specific learning methodologies that override prior beliefs and create new understanding (Carey & Spelke, 2008; Chi, Slotta, & De Leeuw, 1994). Piaget (1985) points to the possibility that change can be achieved by creating an environment where learners are confronted with alternative proposals that are in conflict with their prior conceptual understandings. This cognitive conflict ('*cognitive dissonance*') encourages the student to reflect on the concepts and resolve discrepancies with their own understanding.

2.5 Social Constructivism, Constructionism and Contextualised Learning

Active learning techniques where the student is required to discuss, write and reflect about their learning can trigger intrinsic motivation and increase student engagement (Chickering & Gamson, 1987). Adopting a pedagogical approach that is student centred and encourages active learning can lead to improved engagement in science (Handelsman et al., 2005). Research suggests that students develop complex reasoning and conceptual understanding when they are actively involved with the subject matter and that collaboration also enhances student engagement (Johnson, Johnson, & Smith, 1991).

The idea that learning is essentially a social activity and learning is more effective when learners collaborate and build on each other's knowledge is the foundation of constructivist pedagogies (Piaget et al., 1985; Vygotskiĭ & Cole, 1978). Vygotskii defines the Zone of Proximal Development (ZPD) as the difference between what a learner learns on their own to what they learn as part of a group. Learners build on their own understanding with knowledge obtained through collaboration with others.

Constructionist learning models (Papert, 1993) propose that learning is particularly effective when the learner creates something for others to see. Constructionism and constructivism can be considered complimentary as both are based on the concept of learning as the building of knowledge and when the learner is actively engaged (Harel & Papert, 1991).

The role of context has been the subject of many research investigations. Glynn et al (S. Glynn & Koballa, 2005; S. M. Glynn & Winter, 2004) define contextualised learning as 'using concepts and process skills in real world contexts that are relevant to students of diverse background'. By providing context, students can relate the subject to real world situations and make connections between what they are learning and applications to their own lives (Lye, Fry, & Hart, 2002). Providing context to physics learning will provide relevance and increase student motivation (Bennett et al., 2007; Taasoobshirazi & Carr, 2008).

2.6 Affordance of Technology

There is strong research evidence that changes to the instructional methodologies and pedagogies are required if either conceptual understanding or student engagement is to be impacted. The majority of teaching methods in science classrooms are still anchored in transmissive teacher centred instruction with the text book as the primary source of curriculum delivery. Such methods are not the most appropriate for teaching sciences and fail to integrate appropriate technologies into the instruction (McBride et al., 2010b; Meltzer & Manivannan, 2002).

Students and educators now have access to a range of technologies that afford the ability to capture, present, analyse manipulate and interact with large amounts of information and represent the information in multiple ways (Jonassen, 2000; Richards, 2005; Smeets, 2005). The use of simulations enables a multi-representational view of concepts and physical phenomena with which the learners can interact, change variables and construct their own understanding of the concepts (Jong et al., 1998; Martínez et al., 2011). In simulations both real and abstract concepts can be represented. Learners have the possibility to visualise abstract constructs – molecules, light particles, electrons – and interact with and experiment as to how they behave under certain conditions (Olympiou, Zacharias, & deJong, 2013).

There is a strong body of research that supports the positive benefits of simulations to students studying science (Jong et al., 1998; Smetana & Bell, 2012; Zacharias C. Zacharia, 2005). It also suggests that simulations can be more effective than traditional instruction practices. This positive impact on student learning has been attributed to the multi-representation opportunities that simulations provide rather than the limited representation in traditional laboratory and classroom environments. By uncovering previously 'unseen or hidden' concepts students may gain a far deeper understanding of the phenomenon under investigation. Learners integrate information from these multiple viewpoints afforded by simulations and build up a more complete understanding of the subject being taught (Ainsworth, 2006; Jong et al., 1998). This is only possible in virtual, computer generated environments (Liu & Sun, 2010; Mikropoulos & Natsis, 2011; Trundle & Bell, 2010).

Microworlds provide many features and capabilities that can promote cognitive dissonance, important for developing conceptual understanding. Indeed some researchers have suggested that microworld simulations do so in a way that is more effective than direct experience (Winn et al., 2006). The use of simulations has been used successfully to address the misconceptions chemistry students have regarding chemical bonding with research results indicating improved performance on information retention over the control group (Özmen, Demircioğlu, & Demircioğlu, 2009).

Research into a constructionist design model for computer game based learning (Li, Cheng, & Liu, 2013) examines the influence of constructionism on in three key areas – 1) influence on skill and challenge perception, 2) influence on motivation and 3) influence on learning behaviours. An important aspect of these constructionist simulations was that they contained low threshold – high ceiling activities which allowed novice participants to be engaged while offering continued challenges for users with more expertise.

A useful model for how technology can be used in learning is the **SAMR** (Substitution, Augmentation, Modification & Redefinition) framework proposed by Puentedura (2009). It considers the attributes of the technology to either Enhance or Transform learning. For transformation to occur the technology must allow for significant task redesign (modification) or allow for the creation of new or previously inconceivable tasks (redefinition). However technologies that fall within the Modification or Redefinition category do not align well with traditional classroom settings, where short class duration and teacher centred pedagogies prevail. For learning transformation to occur an alternate pedagogical model is required in which to incorporate these technologies.

2.7 The Bridge21 Model

Growth in information technology and increased digital disorder (Weinberger, 2007) requires a new set of capabilities for students to participate fully in society and employment. Dede (2010) examines the various frameworks that exist for 21st century learning and finds much commonality between them. The emphasis is on critical thinking, problem based learning, collaboration, contextualised learning, creativity and the ability to use technology for learning. Bridge21, a 21st century model developed at this researcher's University, is a technology mediated approach to learning based on social constructivist pedagogy and emphasises collaboration, guided discovery, problem based and contextualised learning. The physical space for learning is an important aspect of Bridge21 and is designed to promote team activities and provide a social setting so that students can feel confident and encourages self-directed learning. The social context of learning is an important component to increasing student motivation and engagement.

By encouraging self-directed learning the role of the teacher becomes one of facilitator and of providing appropriate scaffolding to team based activities. Technology is an integral part of the learning process and student activities will utilise technology in developing solutions, analysis and reporting by students. The team based learning follows the established theory of Vygotsky (Vygotskiĭ & Cole, 1978) and his concept of the Zone of Proximal Development (ZDP). The ZPD is the enhancement to learning a student gains by interacting with other more experienced members in the group to that learned alone.

The Bridge21 model has been applied successfully to STEM based subjects and research into its use in Maths and Computer Science learning has demonstrated a positive impact on student motivation and engagement (Conneely et al., 2013; Lawlor, Conneely, & Tangney, 2010; B. Tangney & Bray, 2013; B. Tangney, Oldham, Conneely, Barrett, & Lawlor, 2010).

2.8 Summary

This chapter has outlined the challenges that exist in motivating and developing students' interest in physics. The prevalence of transmissive teaching practices and the perceived lack of relevance of the subject to their lives are contributing factors to the low levels of student engagement. The literature review also suggests that if physics is taught with the emphasis on mathematical formulae, learners do not develop the level of conceptual understanding required for problem solving.

Evidence is presented for potential strategies that combine social constructivist pedagogy with constructionist and contextualised learning activities. By enabling learners to activity construct their own models which they share with others can lead to improved conceptual understanding and engagement. The affordances of microworld simulations are considered and their potential to incorporate low threshold –high ceiling constructionist activities to impact student engagement discussed.

The chapter concludes with the challenges of implementing microworlds and problem based learning in a conventional classrooms setting. 21st century learning models are examined and Bridge21 proposed as potential learning framework in which to investigate the use of microworld technology.

Chapter 3: Design

3.1 Introduction

The literature review pointed to the potential benefits of microworlds and 21st century pedagogy to impact student engagement and support conceptual understandings in physics. This chapter presents the design of the learning activity to be used for this exploratory case study and examines how it was informed by the literature review.

The first section of this chapter provides an overview of the design of the proposed learning activity. Section two discusses the choice of physics topic to be used during the learning activity. The third section describes the microworld chosen, its key features and selection criteria. In section four the structure of the Bridge21 workshop and how the simulations will be integrated as part of the problem based activity is discussed.

3.2 Design Framework

The importance of conducting a literature review was not simply to provide a status of current activity in this field but rather to inform the design and approach to the learning activity for this research study. The main outputs from the literature review can be defined under four main categories. These categories underpin the design of the physics workshop and the structure and delivery of the learning activity.

These categories are **1)** Pedagogy, **2)** Contextual learning **3)** Technology choice & **4)** 21st century learning model and are summarised in Figure 3-1.

Two main pedagogical models are incorporated into the learning design for this research. The social constructivist model by Vigotskii (1978) suggests that learning are a social activity and that it is more effective when learners collaborate and work in groups. Working in groups challenges the learner and extends their opportunity for further cognitive development. The second aspect underpinning the design is Constructionist learning proposed by Papert (1980). Learning is enhanced when learners are engaged in creating and constructing artefacts that they can share with others. The implications are that the microworld to be used needs to be highly interactive and support the user to construct their own models.

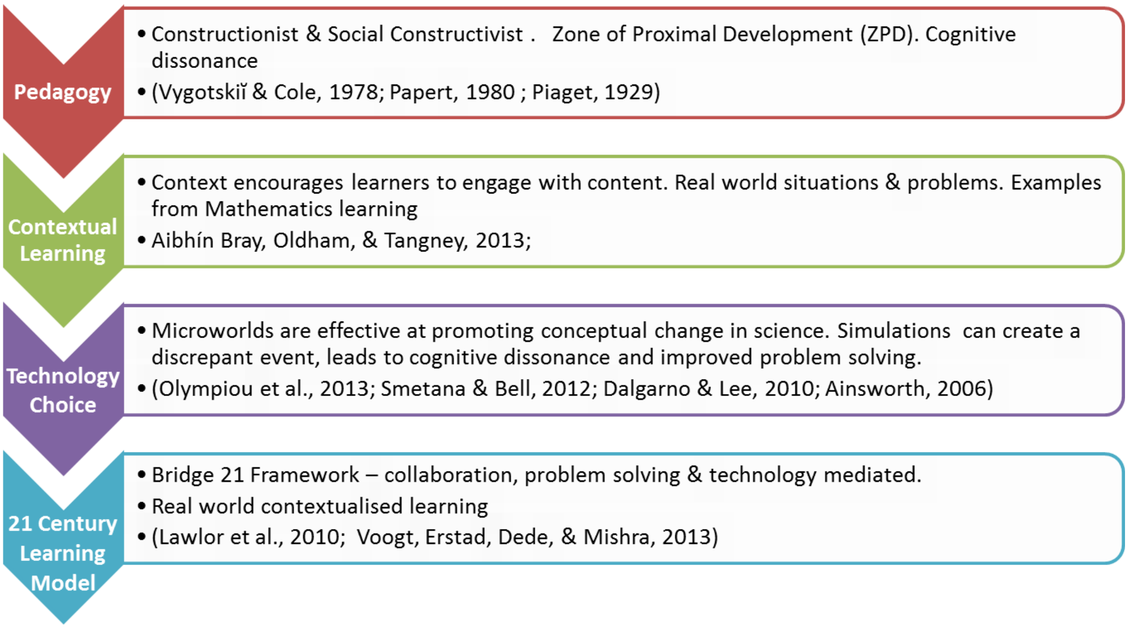


Figure 3-1: Overview of the design framework informed by the literary review.

The impact on engagement and conceptual understanding by contextualising the learning through real world examples and scenarios was presented in the literature review. The combined microworld-Bridge21 activity should allow for real world physics problem to be investigated and enable users take measurements and conduct experimentation. When developing the problem based activity it was to be anchored in a real problem scenario – for example circuit design of Christmas tree lights and car headlights.

The literature has presented the affordances of microworld technology, particularly the ability to represent abstract phenomenon and to allow the 'hidden' to be seen. The researcher reviewed many construction based simulations and microworlds but rejected those that did not enable the user to change variables, measure parameters or to visually represent the abstract.

The final area that informed the design was the evidence that technology mediated, problem based learning did not align well with conventional classroom practices and that Bridge21, a 21st century learning model, is better suited. The case study investigation will be conducted at the Bridge21 facility, a specially designed environment to support the Bridge21 approach. The Bridge21 workshops will incorporate collaborative and problem based activities. The emphasis will be on self-directed activity with the teacher acting as a facilitator.

A detailed summary of the process and alignment of the design with the key literature review references is shown in Table 3-1.

Table 3-1: A summary of the key outcomes from the literature review that have informed the design framework. 4 main categories are considered – Pedagogy, Contextual learning, Technology and 21st century learning model.

Category	Research Reference	Key Points	Design Implications
Pedagogy	(Papert, 1980)	• Constructionism – learning is effective when learner is engaged in creating personally meaning full artefacts	• Select Microworlds that allow learners to create and construct their own models
	(Piaget, 1929)	• Cognitive dissonance – when learner is challenged by a disequilibrium it supports cognitive engagement particularly in problem solving	• Problem based activity should challenge a learner pre conceptions • Microworld features should allow for unexpected outcomes.
	(Vygotskiĭ & Cole, 1978)	• Social Constructivist models – learners learn for themselves and through collaboration and experimentation • Zone of Proximal Development – group challenges the learner	• Group based activity – work in teams • Presentations back to the whole group. Share knowledge and experience. • Technology should support experimentation and making mistakes.
Contextual Learning	(Aibhín Bray et al., 2013) (Aibhin Bray & Tangney)	• RME (mathematics) – based on exploring real world and situational contexts have positive benefit. • Context encourages learners to engage with the content • Problem solving is in real world situation & critical for math understanding	• Christmas Tree and Car light problem - context to problem • Choice of Circuit Construction Kit – allows real models to be created, context to problem and activity
Technology	(Dalgarno & Lee, 2010)	• Affordances of virtual learning environments • Improves engagement, opportunities for experiential learning and contextualised learning	• Choice of PhET Simulations – students can experience building circuits, features allow measurements and immersion in the task
	(Smetana & Bell, 2012)	• Simulations must ensure students focus on the content and not the technology – reduce cognitive load • Teachers role is important when using simulations – guidance, structure to the lesson	• Choice of PhET Simulations – ease of use, low floor • Guided discovery – teachers facilitates, Micro worlds must allow for self-discovery
	(Olympiou et al., 2013) (Ainsworth, 2006)	• Representation of the abstract improves conceptual understanding • Use of simulations with physics students	• Chosen Microworlds must accurately represent abstract and unseen phenomenon – electricity, potential difference etc.
21 Century Model	(Lawlor et al., 2010) (J. Voogt et al., 2013)	• Team based activity • Technology mediated, flexible learning space • Problem based learning activity	• Choice of Bridge21 learning model and structure • Host workshops at Bridge 21 facility

3.3 Overview of the Learning Activity

The microworld selected for use in the study was from the Physics Education and Technology (PhET) project at the University of Colorado. The PhET Circuit Construction Kit was chosen because it allowed for a high degree of interactivity, strong construction capabilities and was highly immersive. The Circuit Construction kit is a low floor–medium ceiling microworld, easy for students to engage with but sufficiently challenging for more advanced users. This ensured it could be as the primary technology resource during the workshop and any problem based activities built around it. Several other microworlds reviewed were very capable at animation of physics phenomena but more passive and not sufficiently deep for a full workshop activity. From a pedagogical viewpoint the selection of microworld was based on the following considerations.

- Allow concrete and abstract representations.
- Constructionist.
- Support cognitive conflict and investigation of alternate models.

The Circuit Construction Kit microworld was incorporated into a 5 hour Bridge21 workshop at the researcher's institution. 3 separate workshops with ~10 students in each were run and formed the basis of this research sample. This together with an initial pilot workshop consisting of 8 participants gave a total sample size of n=39 students.

The Mathematics and Technology Attitudes Scale (MTAS) is a simple data collection tool for middle year secondary students and measures 5 variables related to the learning of mathematics with technology (Pierce, Stacey, & Barkatsas, 2007). These variables are Mathematics Confidence (MC), Confidence with Technology (TC), Affective Engagement (AE), Behavioural Engagement (BE), and attitude to learning mathematics with technology (MT). The MTAS scale has been tested in many situations and has proven to be a reliable tool for data collection. The MTAS questions can be adjusted to examine different technologies. The MTAS questions were also modified to reflect physics as the subject area being examined. The MTAS questionnaires were administered pre and post the Bridge21 workshops. The modified MTAS questionnaire used is shown in Appendix C.

3.4 Selection of the Physics topic for this research

The physics curriculum topic to be used as for the workshop activity is not considered a variable central to the study. However, when designing the learning activity consideration was given to the dependency of the topic on the available microworld and the knowledge level of the participants.

- ***The available microworlds for physics***

For this research study off the shelf, readily available microworlds were to be used. Many microworld simulations reviewed were short interactive animations but lacked the depth of interactivity and construction features required to be used as part of a student workshop. Several construction based microworlds were found in the area of electrical circuit design and these were investigated further for use in the study. A summary of these is given in Table 3-2.

- ***Real world connections & support of problem based activities***

To investigate the impact of microworlds the participants will be using them as part of a contextualised, problem based workshop and it was important that the simulations supported this real world connection. Electricity and circuit design have many applications in a student's environment and given the availability of a microworld covering this area made it a suitable topic for consideration.

- ***Prior knowledge of students***

The participants for this case study will have studied general physics to Junior Certificate level. At this level they will not have sufficient knowledge in more advanced areas such as Quantum & Atomic physics. However they will have covered concepts in electricity and magnetism at junior cycle and this again was a further reason to consider this as a potential topic for the purposes of the study.

3.5 Selection of Microworlds

Software development or microworld creation was not expected to be undertaken as part of this research investigation. Where possible the researcher would use off the shelf, currently available microworlds during this study. The key consideration was to source appropriate simulations that supported all the factors raised by the literature review. Although many microworld simulations exist finding one that was age appropriate, challenging and had a high level of construction features proved more difficult.

5 key factors were taken into consideration when selecting a microworld to use

1. Grade level and appropriateness of the content

The students being investigated for the study were 15-16 year old transition year students. These students have studied a combined general science course (Biology, Chemistry & Physics) for the prior two years and have sat the Junior Certificate exam in 2014. The ability to scaffold the activity and support the introduction of new concepts to the student was an important consideration.

2. Ease of use

Given the relatively short (5 hrs) duration of the workshop any microworld selected needs to be easy to use and require limited time to learn. It needs to have an intuitive user interface that makes key features and interactive components easily accessible to the user.

3. Concrete and Abstract representations

Impacting conceptual understanding requires that the simulations are rich in ability to represent abstract physics phenomena and show concepts that cannot be seen through classroom experiment. Some simulations address this but microworlds can support deeper user interaction and experimentation with these abstract phenomena.

4. Interactivity and Construction Capability

For the purposes of this investigation students need to be able to construct new models, take measurements to help support their understanding and confirm their conceptual model is plausible. Finding microworlds that had this high level of construction features to them was a challenge and narrowed down the available choice considerably. Some with construction and interactive features were examined but excluded due to poor usability or suitability for the grade level of the participants being considered in the research.

5. Efficacy and accuracy of underlying modelling theory

For the learner to construct their own representations and model real world situations it is important that the underlying principles of the microworld are based on accurate physics theory. Any measurements taken with tools in the microworld should reflect real world scenarios. The efficacy of the microworld needed proven.

Using the criteria above the research investigated the suitability of a range of simulation software available for free on the web. The main ones considered are summarised in Table 3-2 below.

Table 3-2: Summary of the microworlds considered for this research study and criteria use for selection.

Simulation Name	Organisation & Access	Key Features & Reason for not Using
PhET Simulations	University of Colorado at Boulder. https://PhET.colorado.edu/	**Features:** very broad set of simulations 100+ models. Accurately represent the physics theory. Simple Interface. **Selected:** Circuit Construction Kit – represents abstract concepts, full feature set, easy to use, high degree of construction and measuring capability.
SimPhysics	Institute of Physics http://www.iop.org/education/teacher/resources/sim/page_41572.html	**Features:** Game based simulations targeted at 13-16yr olds. Limited to 4 games, 3 subject areas – space, environment & sound **Rejected:** Limited ability to represent abstract concepts, narrow selection, and interface was older design. Targeted at younger age group.
Quite Universal Circuit Simulator (QUCS)	Open source simulator. http://qucs.sourceforge.net/	**Features:** extensive circuit components and measurement. Open source software. Aimed at circuit design professionals. **Rejected:** too advanced for purposes of workshop. Requires time to learn tool set. Not capability to simulate abstract concepts. Open Source and limited efficacy and accuracy evidence
Do Circuits	Commercially developed. http://www.docircuits.com/#home	**Features:** Full circuit design capability, extensive functionality and components. Models actual circuit construction. Fee based model. Suitable for advanced circuit design students. **Rejected:** Too advanced for age group and prior experience of the workshop participants -Does not support abstract concept representation

Considering the selection constraints outlined above, the PhET Circuit Construction Kit, from the University of Colorado was considered the most suitable for the research being undertaken. PhET simulations also support varying degree of interactivity where a student may move objects, change parameters and take measurements. However finding a suitable simulation that supported a construction activity was the most challenging. Only the circuit Construction Kit microworld from PhET met this need.

3.6 The PhET Program

The Physics Education Technology (PhET) project at the University of Colorado has for several years been investigating the application of simulations to support the teaching of science and in particular physics. Today the PhET project has developed over 100 research based simulations covering both introductory university and secondary school (High School) physics and chemistry curricula. The PhET project is a non-profit activity and all the simulations are available for free download or run directly from the PhET website (https://PhET.colorado.edu/). The simulations are all open source and written in Java, HTML5 or Flash. Most simulations can be run on both desktop and tablet devices and on the main operating systems – Apple iOS, Google Android and Microsoft Windows.

All the PhET programs are designed with a strong research based approach and incorporate current user experience and design principles (Noah Finkelstein, Adams, Keller, Perkins, & Wieman, 2006).

They are designed to engage students, support understanding of key concepts in physics and relate to real world situations. PhET models help students understand concepts through discovery and play. The simulations provide immediate feedback to the user as they change variables and through the use of tools users can take measurements and confirm their own construct of the particular phenomenon is plausible.

The PhET simulations employ a constructivist approach, building on a learner's prior knowledge and scaffolding activities. Another aspect of the PhET simulations is that they provide rich visual models of the concepts and make the abstract explicit. This encourages students to gain a deeper understanding of physical phenomena that otherwise remain unseen.

3.7 PhET Circuit Construction Kit Microworld

For the purpose of this study the PhET Circuit Construction Kit simulation was selected based on the criteria and constraints outlined earlier. The Circuit Construction kit allows students to build simple circuits with a selection of components that are familiar to secondary level students. Components available include DC battery source, AC voltage source, resistors, capacitors, light bulbs, switches and a selection of everyday items to investigate (pencils, coins etc.). Users have full control over how they use these components and are free to design circuits however they wish.

The Circuit Construction Kit microworld models real electric circuit laws, using Kirchhoff's laws for voltage and current flows in electric circuits. This provides and authentic setting in which to experiment. Students have access to a virtual circuit board where they can place wires, switches resistors, capacitors and other components to design a circuit of their choice. All components have default parameters that model real resistors wires and batteries. One advantage of PhET is that users can freely adjust parameters and explicitly see and measure the impact of these changes. Students can use the ammeter and voltmeter to take real voltage and current measurement in the circuit. Through graphical representation they can also explore fluctuations of the current and voltage in real time.

The Circuit Construction Kit also provides visual representation of electron flows in the circuit they have designed and how these flows are affected by different value resistors, capacitors and voltage sources. Users can also speed up and slow down the visual animation which is particularly useful depending on their specific circuit design.

As students are creating their circuit designs they can save their project for later editing and sharing. This feature is particularly useful for our workshops where students will be asked to present back on their findings and reflect on the choice of circuit design they have made.

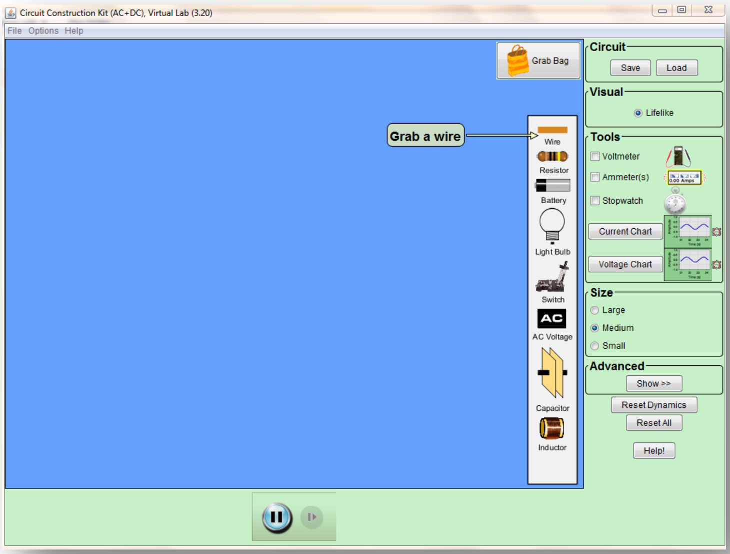


Figure 3-2: Start up screen for the PhET Circuit Construction kit microworld. User interface is simple, with a clear layout of the measuring tools and options available for the user to explore.

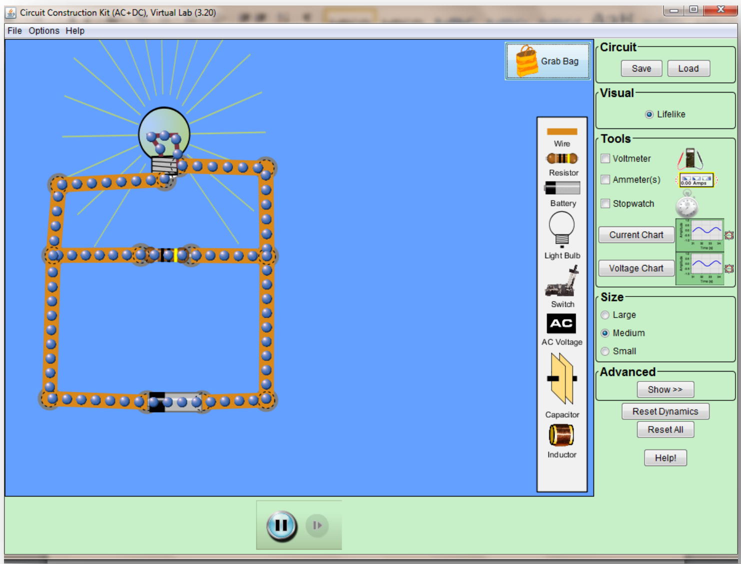


Figure 3-3: A simple circuit design. Dots in wire represent the 'abstract' electron flows which move in the live environment. Users are provided with immediate feedback – e.g. bulb lights up.

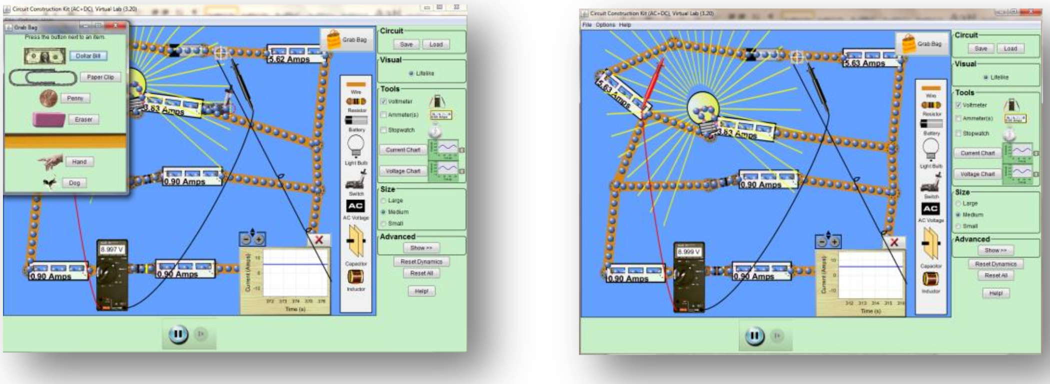


Figure 3-4: PhET Circuit Construction Kit illustrating more complex circuit design. User has access to accurate measuring tools such as ammeters, voltmeters and results are immediate.

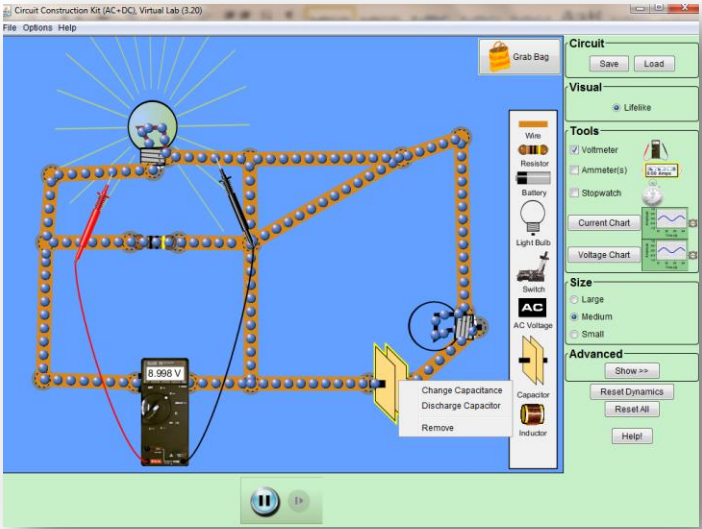


Figure 3-5: By right clicking on any component or junction additional commands become available to the user. Here the option to change the value, remove or discharge a capacitor is shown.

3.8 Bridge21 Learning Model

Implementing a technology mediated, collaborative and problem based learning activity in conventional classrooms faces many challenges. Short class durations and didactic pedagogy do not support student centred, self-discovery activities. In an Irish context the problem is exacerbated by the focus on teaching to the curriculum in preparation for high stakes state exams.

By contrast 21st century learning models (Dede, 2010; J. Voogt et al., 2013) described earlier are more suited to the integration of the selected microworld into the learning activity. Bridge21, a particular implementation of a 21st century learning model, has been shown to be a suitable framework in which to integrate technology, contextualised learning and 21st century principals (problem based, collaborative). Research into the Bridge21 model has shown strong impact on student engagement and appreciation of mathematical content (Aibhín Bray et al., 2013). Tangney et al (B. Tangney, Bray, A., & Oldham, E., 2015) have demonstrated positive learning outcomes when mobile technology and contextualised realistic mathematics education (RME) are integrated within the Bridge21 pedagogical framework.

The Bridge21 environment is based around flexible and configurable physical learning spaces. Seating, workstations and computers can be easily rearranged depending on the activity, Figure 3-6. Bridge21 provides a suitable pedagogical framework with which to combine the microworld technology.

Figure 3-6: The Bridge21 learning space. Workstations are fully configurable and can be easily rearranged to suit specific needs. Large monitors support sharing of circuit models to the group.

3.9 Summary

This chapter has described how the learning activity was designed in order to address the research questions proposed in Chapter 1 - the impact of microworlds in a 21st century learning environment on student engagement and confidence in physics. The secondary research questions regarding the impact on students' attitudes to the use of microworld technologies to teach physics and also how these can be scaffolded as part of a 21st century learning model is also taken into consideration during the design stage. The early section of the chapter outlines how this design was informed by the literature review and the criteria used in selecting and an appropriate microworld for this case study.

Chapter 4: Research Methodology

4.1 Introduction

The PhET Circuit Construction Kit microworld used in this research study was selected because it supported a constructionist approach, affording a high level of interactivity and immersion by the user. It gives immediate feedback to the user on the validity of their representations and appropriate measuring tools aid conceptual understanding. The Bridge21 learning model, structured around workshops of up to 5 hours duration, is a suitable framework in which to integrate the PhET microworld simulations. By using appropriate pre and post activity questionnaires it is proposed that any impact resulting from the physics workshop can be measured over these timeframes. A convergent mixed method case study methodology was used for the research investigation with both quantitative and qualitative data collected. This chapter discusses the elements that informed the methodology, their inter-dependencies and the data collection and analysis instruments used.

4.2 Research Questions

The methodology was designed to help address the research questions under investigation. The participant sample size needed to be large enough to infer any statistical significance from quantitative data gathered. The main and secondary research questions being asked are

1. How do microworlds, when used as part of a 21st century learning model, impact student engagement and confidence in physics?

2. Do microworlds impact students' attitudes to learning physics with technology?

3. What factors need to be considered if microworlds are to be integrated into conventional classroom environments?

It is important that that any data collection instruments allow for quantitative analysis and as well as providing qualitative insights. The MTAS (Mathematics & Technology Attitudes Scale) was adopted as the questionnaire framework for quantitative data gathering. Qualitative data was collected through focus groups and observation during the workshops. Through a convergent analysis of both sources of data the research questions could be addressed.

4.3 Research Model: Mixed Methods Case Study

A convergent parallel mixed method case study was chosen for the research methodology (Creswell, 2013). The case study methodology is appropriate as it allows for an in depth investigation of one particular area over a relatively small sample size (n=39 for this study) and the results to be discussed in a broader context. The mixed method requires both quantitative and qualitative data to be collected, analysed and congruence between the two data categories to be examined.

The methodology used during this research was developed to ensure the resulting data addressed the research questions and each stage was informed by outputs from prior stages. A schematic of the methodology is shown in Figure 4-1.

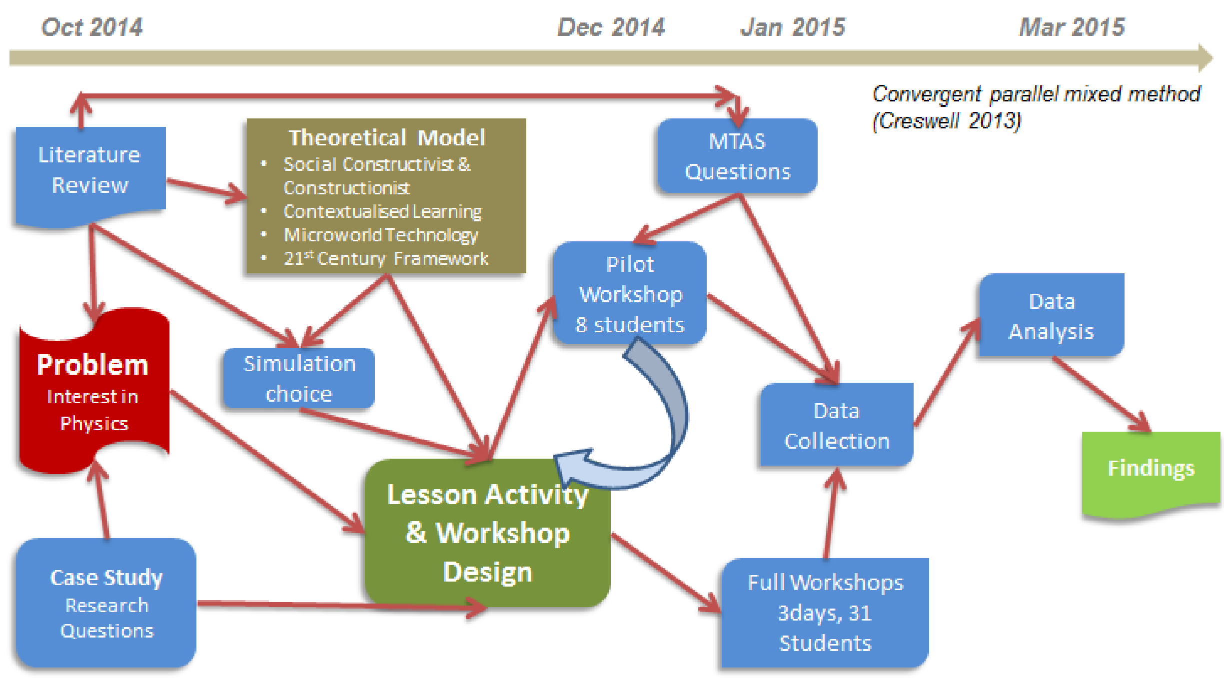


Figure 4-1: Representation of the research methodology and timeline. The interrelated nature of the stages helped ensure outputs from one activity informed the next.

The starting point is the problem statement which was researched in the literature and discussed in Chapter 2. The literature also informed the theoretical model underpinning this research and based around the four pillars –Social Constructivism & Constructionism, Contextualised learning, microworld technology and a 21st century learning framework. A pilot workshop was run to test the appropriateness of the model and the structure of workshop activity prior to the three main workshops.

4.4 Implementation

Three full day workshops were run at the Bridge21 facility with ~10 students attending each workshop. Different students were involved each day giving a total of 31 participants. A pilot workshop was also run prior to the first full workshop with an additional 8 participants attending.

Participants were from 4th year (transition year cycle) in Irish secondary schools. The 38 students represented five schools from the Dublin area. Many of the participants had attended Bridge21 workshops in the past and were already familiar with the structure and team collaboration elements. This helped ensure that the investigation could focus on the use of microworlds and was not overly influenced by the novelty of the Bridge21 experience for students. Students from different schools had not previously met each other so an icebreaker activity was conducted to facilitate team formation and collaboration.

Ethics approval was required from the university prior to conducting any research with participants. The ethics submission was approved by the University's Research Ethics Committee on December 05th 2014. Details are provided in Appendix I.

4.4.1 Pilot Workshop

A pilot workshop was run at the Bridge21 facility in December 2014 approximately 6 weeks prior to implementing additional workshops. The aims of the pilot workshop were

1. Determine suitability of the PhET Circuit Construction Kit
    a. Did the microworld have sufficient depth and construction capabilities to keep students active during a 5 hour workshop?
    b. Could the microworld be the primary technology used for the problem based activity?
2. What was the optimal group size to ensure participants could use the simulation and contribute to the activity?
3. Determine optimal timings and flow for activities.
4. Evaluate level of scaffolding support required based on students prior knowledge of circuit design (new mathematical concepts for circuits in series and parallel were being introduced to participants).
5. Assess format of pre and post activity questionnaires.
6. Refine focus group interview methodology and questioning.

The pilot workshop was structured along standard Bridge21 workshops design, as shown in Appendix A. The pilot workshop ran very smoothly and integration of the PhET microworld in the Bridge21 model occurred without problems. The main learnings from the pilot related to questions 2) and 6) above. During the pilot, groups contained 3 people at each workstation which led to difficulty in keeping everyone involved and active. Midway through the pilot group sizes were reduced to 2 people and this resulted in an observed improvement in collaboration and level of engagement by all participants. The pilots also highlighted the need for improved questioning during the focus group, with appropriate clarification and follow up questions.

4.5 Data Collection Techniques

A mixed methods case study was selected for this research investigation and data was collected using a variety of procedures during the workshops. Quantitative data was collected from the modified MTAS questionnaire while qualitative data was gathered through pre and post questionnaires, focus groups, observation and student output during the workshop activities. The modified MTAS questions are shown in Appendix C. Using the categorisation of Creswell (Creswell, 2013) this case study can be defined as a *'convergent parallel mixed method design'*. Qualitative and quantitative data have been collected at the same time, allowing for both to be analysed separately but will be triangulated to provide deeper insight into the research questions. This triangulation of the data has been incorporated into the data analysis procedures.

Data was captured during the 3 workshops and during the initial pilot. Although the pilot workshop was run to help validate the design of the learning activity, the changes made between pilot and full workshops were refinements and not fundamental changes to the design. No changes were made to the MTAS questionnaire and only additional open ended questions were added to the pre and post workshop questionnaires. For the purposes of data analysis the outputs from the pilot and the 3 workshops will be combined, with the pilot being considered as a 4th full workshop. 31 students participated in the workshops and 8 different participants were involved in the pilot. Thus the sample size for this research investigation is n=39 participants which for any statistical analysis is a good sample group. One participant failed to complete the pre workshop MTAS questionnaire. This participant's data was removed from the any subsequent MTAS data analysis, resulting in a sample size n= 38 for statistical analysis.

A variety of qualitative data was collected through open ended and Likert style pre and post questionnaires. The questions were designed to collect information on areas such as participant's education background, science subjects being studied, and reasons for not choosing physics and to understand further their views on the use of the computer simulations. Observation data was recorded (video & photo) particularly during student presentations. Saved PhET circuit design files have been collected, as well as group PowerPoint slide presentations. Examples of this working student content is shown in Appendix B

4.6 Data Preparation

Prior to any analysis being undertaken careful consideration was given to reviewing completed questionnaire forms and preparing the data collected into a form that would facilitate accurate analysis. MTAS questionnaires were read and reviewed for accuracy and completeness. It was during this process that one student pre MTAS questionnaire was rejected as being incomplete and this student data removed from the sample. Each MTAS questionnaire was accurately collated. Students completed the survey on paper and marked their Likert section with a check mark. The pre and post surveys were hand marked directly on the completed questionnaire form using a 5 point marking system for each question selection with 1 for Strongly Disagree up to 5 for Strongly Agree. The results from the hand marking were then entered into Microsoft Excel for easier formatting and extraction. With 39 respondents and 20 questions for each there was a significant amount of data to be transferred and matched correctly. The researcher felt that in this data transcribing there was potential for personal error to creep into the process and so asked a second person to review and match the original filled questionnaire with the data in Excel. With the data in Excel it could be grouped into the relevant MTAS subcategories such as Affective Engagement (AE), Behavioural Engagement (BE), Physics Confidence (PC) and these results matched for pre and post data against each unique student number. Once in Excel a quick check could be done to ensure that data scores were valid, with student MTAS scores not exceeding 20 for each subcategory or 100 in total. An example of the raw Excel data is shown in Appendix D.

Focus group interviews were run immediately after each workshop and no further access to the participants was possible once they completed the day workshop. Each focus group comprised of between 4 and 6 participants and the discussion was recorded using a smartphone recording app. 8 separate focus group discussions were recorded each lasting approximately 10mins, with the longest just over 12mins in duration. This yielded well over an hour of data to be analysed.

Each of the focus group recordings was carefully transcribed and time stamped to allow for reading and coding. During transcribing individual names were not assigned to the responses but continuity of the responses was maintained so that it was clear when a follow up point was made if a respondent was interrupted. If a word or part of the conversation was not audible or clear it was left blank (marked *unintelligible*) on the transcribed document. To maintain validity of the data no attempt was made to guess at what the respondent was trying to say.

Printed copies of the focus group content were used during the hand coding process. A sample of one of the focus group transcripts is shown in Appendix G

4.7 Convergent Analysis

Two distinct data collection and analysis procedures were used during this research. The modified MTAS questionnaire provided the quantitative data which was statistically analysed using Paired t-test procedures. This gave a statistical measure of any impact the workshop had on the 5 MTAS subscales –Affective Engagement (AE), Behavioural Engagement (BE), Technology Confidence (TC), Physics Confidence (PC) and Attitudes to using technology for physics learning (PT).

The transcripts of the focus groups were coded using two separate approaches – Open coding and Directed coding. The open coding allowed themes to emerge naturally from the transcripts while in the second approach the MTAS subscales were used to direct the coding.

The final stage in the analysis was to search for congruence between the quantitative and qualitative data. This results in greater level of corroboration of the findings from the research and also helped highlight areas worthy of further investigation. The Data Analysis procedure is summarised in Figure 4-2 below.

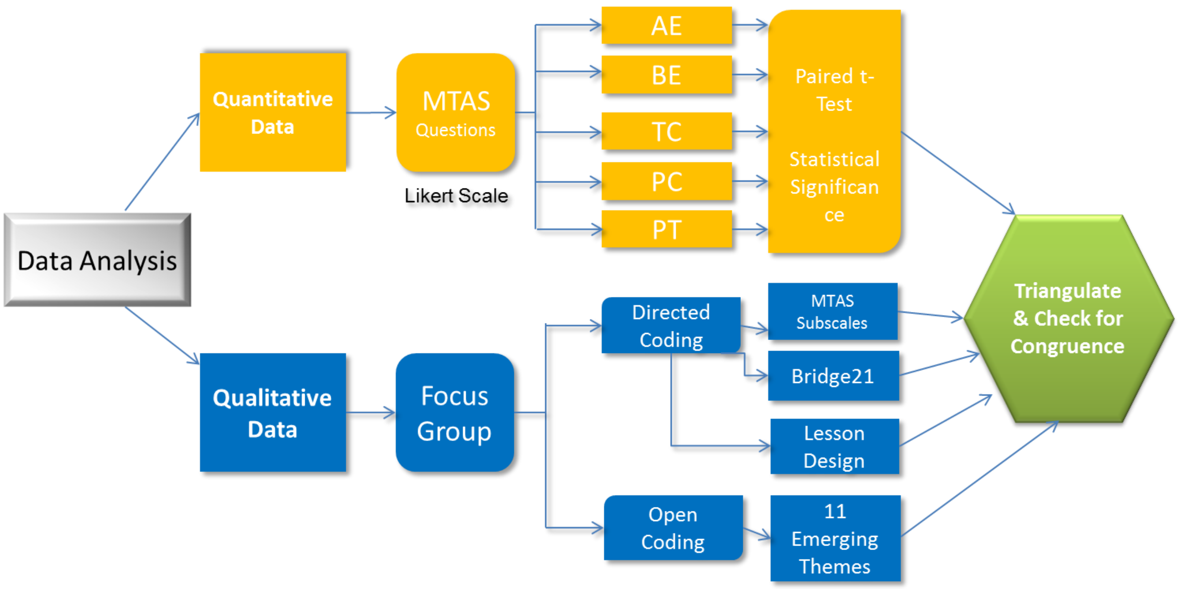


Figure 4-2: Data analysis framework used in this parallel mixed method case study. Congruence between quantitative and qualitative data supported research conclusions.

4.8 Summary

This chapter has outlined the evaluation methodology used to address the research questions posed in this study. The interconnection between many stages in the process is discussed and how the overall methodology was underpinned by a theoretical framework informed by the literature review. The use of a pilot workshop to help validate the methodology and identify areas for improvement was also discussed. The importance of the data collection and analysis techniques was presented and how the triangulation of quantitative and qualitative data would be approached.

Chapter 5: Data Analysis & Findings

5.1 Introduction

This chapter presents the results of the data analysis and discusses findings that arise. The statistical analysis of the MTAS data is first discussed and initial findings for each of the MTAS subscales presented. The chapter then examines the results from the Open and Directed coding of the focus group transcripts and the initial findings for this data path discussed. A convergent analysis is the presented for the quantitative and qualitative paths and the findings of any congruence considered. Finally the chapter examines potential limitations of the work and outlines areas that may warrant further investigation.

5.2 Data Analysis

5.2.1 MTAS Survey - Statistical Analysis

The MTAS data was analysed using SPSS and a **Paired t-test** used to look for the differences between means of a pre and post activity sample. The t-test is suitable for small samples and works on the basis of the null hypothesis which says that if the difference between two means is zero there is no significant difference between the samples. The paired t-test is recommended for sample sizes over 30 so this research investigation sample, n=38, is above the limit.

For an initial statistical view of the pre and post survey data means and standard deviations were calculated. This was done across each of the five MTAS categories – Affective Engagement (AE) Behavioural Engagement (BE), Technology Confidence (TC), Physics Confidence (PC) and attitudes to the use of technology in physics learning (PT). This data presented in Table 5-1 below shows increased mean scores in the post questionnaire data in each of the five categories. The attitude to the use of technology in learning physics (PT) shows the largest gain in means from 13.10 pre activity to 17.02 post activities. Also with a post activity standard deviation the student scoring is more tightly focused around the means and shows less spread in scores than pre activity.

All data analysis was carried out at a 95% confidence interval setting in SPSS. This is the normal confidence interval used in the majority of statistical analysis and is sufficiently tight for the purposes of this research.

Table 5-1: Mean and standard deviation data for pre and post workshop questionnaires for each of the 5 MTAS subcategories.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	BE Post	15.6579	38	2.33974	.37956
	BE Pre	14.9737	38	2.71619	.44062
Pair 2	TC Post	14.8158	38	3.27030	.53051
	TC Pre	14.3947	38	3.38150	.54855
Pair 3	AE Post	15.8684	38	2.77217	.44971
	AE Pre	14.6316	38	3.24180	.52589
Pair 4	PC Post	13.6842	38	3.32968	.54015
	PC Pre	12.5000	38	4.22828	.68592
Pair 5	PT Post	17.0263	38	2.62511	.42585
	PT Pre	13.1053	38	3.05614	.49577

The results of the Paired t-test are shown in Table 5-2. The t values are calculated using the difference between means (x) standard deviation (s) and the sample size (n) according to the equation

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

The t value takes into account the sample size so that any significance inferred in the analysis has been adjusted for sample sizes.

To interpret significance in the calculated t value the researcher consulted standard published t tables for 95% confidence intervals and 37 degrees of freedom (n-1) and determined that a t value greater than 2.021 is significant.

Examining the t values in Table 5-2 shows that 4 of the 5 MTAS subcategories show significant positive differences after the workshop. The four areas are Affective Engagement (AE), Behavioural Engagement (BE), Physics Confidence (PC) and Attitude to the use of technology in teaching physics (PT). For PT (t=6.894) the change was very significant and participants had a positive reaction to the PhET Circuit Construction Kit microworld. Only Technology Confidence (TC) with t= 1.275 showed no significant change pre and post workshop activity.

Table 5-2: Results of the paired t-test analysis on the pre and post workshop MTAS questionnaires. At 95% confidence interval a t value greater than 2.021 is significant.

		Paired Differences					t	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference			
					Lower	Upper		
Pair 1	BE Post - BE Pre	.68421	1.67824	.27225	.13259	1.23584	2.513	.016
Pair 2	TC Post - TC Pre	.42105	2.03525	.33016	-.24792	1.09002	1.275	.210
Pair 3	AE Post - AE Pre	1.23684	2.18637	.35468	.51820	1.95549	3.487	.001
Pair 4	PC Post - PC Pre	1.18421	2.16677	.35150	.47201	1.89641	3.369	.002
Pair 5	PT Post - PT Pre	3.92105	3.50584	.56872	2.76871	5.07339	6.894	.000

5.3 Qualitative Data Analysis

A mixed methods research design was chosen for this investigation with equal importance being placed on the collection of qualitative data and quantitative data. Both forms of data were collected during the Bridge21workshops. Much of this qualitative data is unstructured and the researcher took careful steps to prepare the data for analysis. There are many approaches to analysing unstructured data that have been outlined in the literature (Creswell, 2013; Sapsford & Jupp, 2006) and for the purposes of his research several approaches will be employed. This will allow the data to be analysed from different perspectives and ensure that any richness in the data can be extracted to give deeper insight and validate the quantitative findings.

Two focus group sessions were held at the end of each workshop with over 70 minutes of discussion recorded. Although there was a structure to the interviews, it was also important to allow the participants express opinions and allow the researcher to follow up with clarification questions that could provide further insight.

The first pass over the data involved a Directed Coding technique using the MTAS categories as a framework for the coding process. The second approach was to allow themes to emerge through an Open Coding process and not be constrained by any predetermined framework. During the Open Coding process a combination of invivo and descriptive codes were used (Saldaña, 2012). Hand coding techniques were used for both Directed and Open coding process. Consideration was given to using the qualitative analysis software, NVivo from QSR International. However NVivo requires time for the user to become proficient and given the short timeframe to complete this research project it was discounted. This researcher also preferred to conduct a manual, hand coding analysis as it was felt this would give a closer connection with the raw data from the focus groups and possibly a deeper understanding of what respondents were saying.

5.3.1 Directed Coding Analysis

The goal of the directed coding process was to identify students' positive or negative perceptions against the MTAS categories from a perspective of both their existing school teaching methods or from the physics workshop. From initial reviews of the focus group transcripts it was clear that participants has strong feelings and opinions about how physics was taught in their schools and so directing the coding to both of these areas was worthwhile. The detail of the coding framework is shown in Table 5-3. For each of the 8 focus group transcripts the researcher identified statements that aligned with the theme and manually coded it on the transcript document with the appropriate coding abbreviation. For example a statement by a student such as

> *'I thought it was good. It was more fun'*

was coded $\alpha 3$ as a positive reaction to the physics activity for Affective Engagement (AE).

Another statement

> *'Yeah. Before I came I had no clue about physics and then I learned loads as well -'*

was coded $\delta 4$ against Confidence in Physics (PC) and $\beta 3$ for Behavioural Engagement (BE).

Two additional categories were considered for the directed coding analysis. These related to the 21st century learning environment (Bridge21) and the design of the physics activity (Lesson Design). Themes such as collaboration, self-directed learning were looked for against the Bridge21 category and for Lesson Design the themes related to students opinions on how well the activity was designed, scaffolded and structured and also feedback on ways to improve it.

A sample of the marked up transcription for directed coding is shown in Appendix E.

Table 5-3: Summary of the Directed Coding Framework used for focus group transcript analysis

Code	Subcategory	MTAS category	Themes
α1 α2 α3 α4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	AE	How they feel about physics Bored, enjoy, fun
β1 β2 β3 β4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	BE	How they behave Learning behaviour Level of effort Concentration Stick with it – find a solution Link new with existing knowledge Enjoy problem exercises
χ1 χ2 χ3 χ4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	TC	Feel self-assured with technology Can master if required Can resolved problems
δ1 δ2 δ3 δ4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	PC	Perceptions of their ability Perceptions of their achievements, to do well Ability to handle difficulties Work hard will get good results Comparison with other subjects
ε1 ε2 ε3 ε4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	PT	Technology provides relevance to physics learning Technology enhances learning Provides different perspectives Simulations are helpful
ϕ1 ϕ2 ϕ3 ϕ4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	Bridge 21	Self-directed learning, Collaboration Team based Problem based activity Physical environment
κ1 κ2 κ3 κ4	School Method Pos School Method Neg Physics Activity Pos Physics Activity Neg	Lesson Design	Support Scaffolding, guided instruction structure timing topics covered

The initial coding process for all transcripts was completed during the course of a single day to maintain consistency in the definition of the codes for the researcher conducting the coding. Some days later these marked up transcripts were then reviewed against the coding framework to ensure correct mark up and any errors corrected. The frequency of occurrence of each code was recorded on the transcript sheet. This data was then transferred to Microsoft Excel for further analysis. Several checks were made to minimise any potential error creeping in during the conversion of data from the transcripts to Excel (Table 5-4).

Table 5-4: Frequency results from the directed coding against each subcategory.

	Code	Sub Category	Frequency
AE	α1	School Method Pos	1
	α2	School Method Neg	27
	α3	Physics Activity Pos	39
	α4	Physics Activity Neg	0
BE	β1	School Method Pos	0
	β2	School Method Neg	12
	β3	Physics Activity Pos	31
	β4	Physics Activity Neg	0
TC	χ1	School Method Pos	1
	χ2	School Method Neg	0
	χ3	Physics Activity Pos	0
	χ4	Physics Activity Neg	0
PC	δ1	School Method Pos	4
	δ2	School Method Neg	39
	δ3	Physics Activity Pos	56
	δ4	Physics Activity Neg	2
PT	ε1	School Method Pos	0
	ε2	School Method Neg	33
	ε3	Physics Activity Pos	59
	ε4	Physics Activity Neg	2
Bridge21	ϕ1	School Method Pos	0
	ϕ2	School Method Neg	18
	ϕ3	Physics Activity Pos	35
	ϕ4	Physics Activity Neg	0
Lesson Design	κ1	School Method Pos	0
	κ2	School Method Neg	0
	κ3	Physics Activity Pos	6
	κ4	Physics Activity Neg	36

Presenting the data in graphical form (Figure 5-1) we see that there are high frequencies relating to negative school experience and positive workshop experience across Affective Engagement, Behavioural Engagement, Confidence in Physics, Attitude to the use of Technology in learning physics and Bridge21.

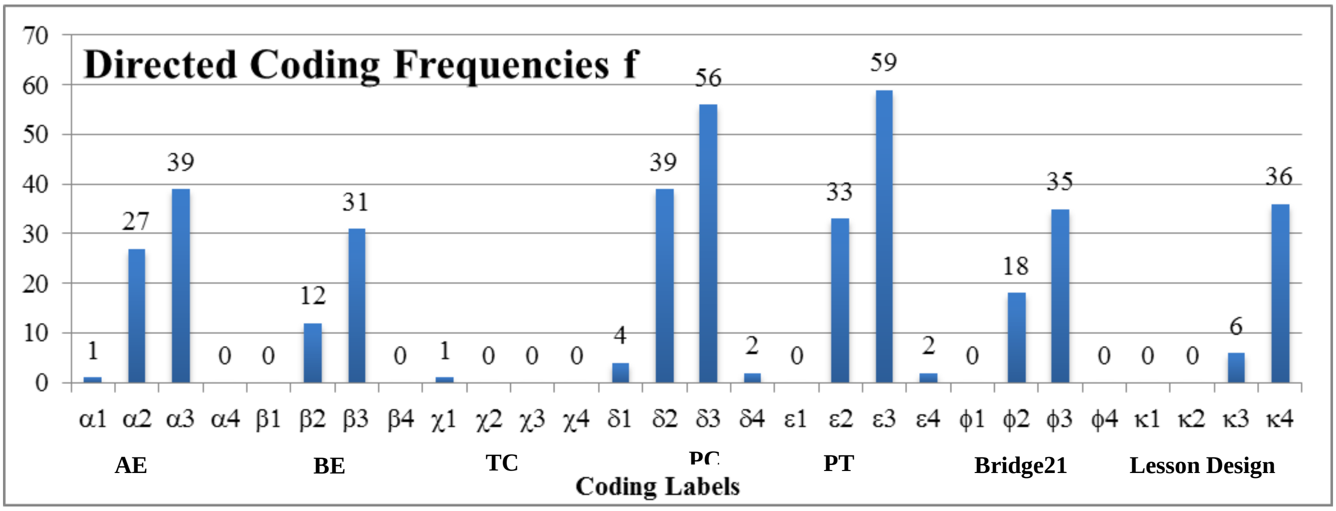


Figure 5-1: Graph showing the frequencies resulting from the directed coding of the focus group transcripts.

Respondents had very strong views and insight to provide on their experience of the physics workshop with many positive experiences (ε3 f=59) in using the technology (PhET microworld) during instruction and many positive comments (δ3 f=56) relating to their improved confidence in physics following the workshop.

It is clear from the graph that many of the participants had quite negative views of how science or physics is currently being taught in their school and this had a strong impact on their affective engagement (α2 f=27), their confidence in physics (δ2 f=39) and views on how technology is being deployed (ε2 f=33).

Positive experience (ϕ3 f=35) of the Bridge21 model with a focus on collaboration, problem solving and contextualised learning was in contrast to the high negative comment for learning styles in their own schools (ϕ2 f=18).

For the category Lesson Design the focus groups yielded good insight as to what the students liked about the workshop structure and areas for improvement. The κ4 coded comments (f=36) were not negative about the activity but rather gave suggestions as to how it could be improved. Many participants suggesting that the workshop should have been longer and contained more content areas in physics.

5.3.2 Open Coding Analysis

A second coding of the transcripts was carried out using Open Coding techniques. This process allowed themes to immerge naturally from the focus group data. A series of iterations was required in the coding process to extract themes and group into common categories.

In the first phase the transcripts were read and marked up with words that helped define what was said in a sentence. These words were either defined by the researcher or taken invivo from the transcripts. This first mark-up generated over 100 words or themes across the 8 focus group transcripts. A sample of the open coded marking is shown in Appendix F. The transcripts were reviewed and the frequency of the occurrence of these themes recorded. Where there was an overlap or similar code words the data was combined. This reduced the list of code statements down to 56 and examples of the top 20 statements and their frequencies given in Table 5-5.

Table 5-5: The table shows the frequencies of occurrence of the top 20 emerging themes from the Open coding analysis of the focus group transcripts.

Emerging Themes	Frequency
Structure of lesson	26
Books	25
Conceptual understanding	20
Simulations	17
Constructions	14
Contextual	14
Visualise	14
Maths v physics	12
doing	11
Experimenting	11
Self-directed	9
+ affective engagement	8
Prior school experience	8
Collaboration	6
Engagement	6
Fun	6
Easier	5
Hard subject	5
Prior feelings	5
Didactic	5

The next iteration of the data reduced this list of 56 words/statements into 11 themes. Figure 5-2 shows the frequency of occurrence of these 11 grouped themes during the analysis.

Many of the respondents mentioned the prevalence of books for learning science in their school and the majority indicated that they were not engaged by the content and found it ‘boring’.

'Because when you are looking at a book I just feel that nothing is going in'

'The simulations helped you learn better, you could see it rather than just reading about it'

For the purposes of the coding analysis statements such as this were themed under School Teaching methods. This theme had the highest frequency (f=59) and in the majority of cases the statements were negative.

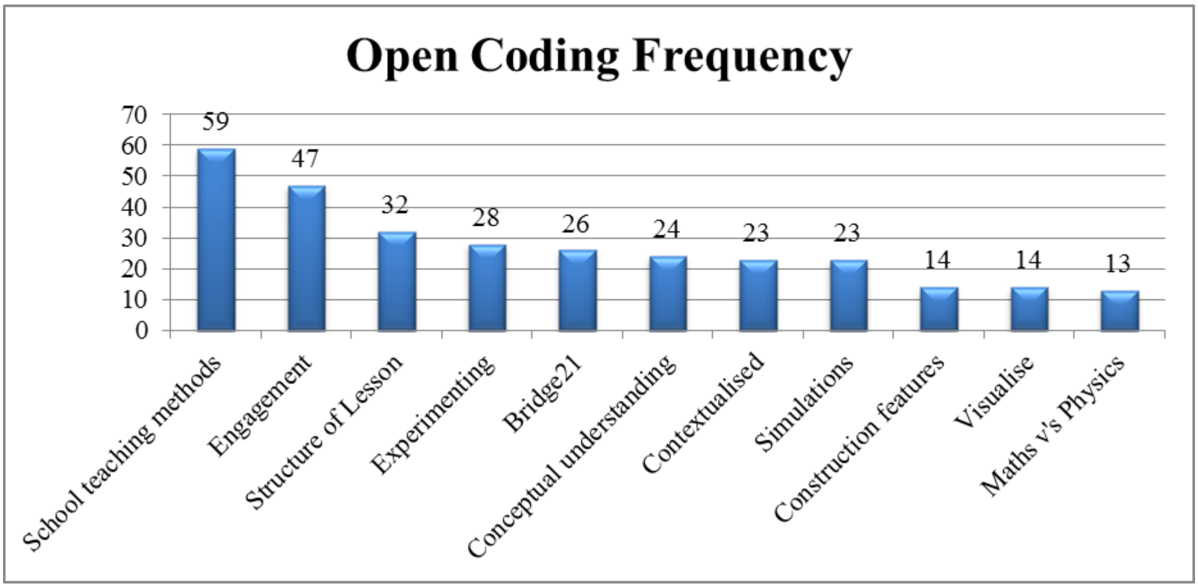


Figure 5-2: Frequency of occurrence of themes emerging from the open coding analysis of the focus group transcripts.

5.4 Findings

This section will present the findings from the quantitative and qualitative data analysis described earlier. Congruence between both sets of data is examined to support confirmation of findings from either source.

5.4.1 Affective Engagement (AE)

The Paired t-test scores (t=3.487) for affective engagement showed statistically significant differences between pre and post scores for the physics workshop. This MTAS subcategory had the second highest change as a result of the workshop. This positive change is also supported by the directed coding of the focus group sessions as outlined in Figure 5-1. The focus groups give an insight as to potential reasons for this positive change. Participants expressed strong negative opinions about how science is taught in their school. The 39 participants represented five different schools in the Dublin area and would suggest a common problems rather than specific to an individual teacher. The prevalence of text books as the source of curriculum and the didactic teaching practice were the main concerns expressed.

'Basically all we did was take out our books, take down notes and do—that's it really. It was really boring. There was no fun to it at all'

'With a teacher just standing at the top of the class and talking down to you'

'In our school you just kind of sit there and you read through the whole chapter. You just read through it. Like half the time we don't even get questions to do or anything'

The most common theme to arise from the Open Coding process related to Current School Teaching methods (f=59) and in the majority of cases the comments addressed negative issues. The directed coding process however also generated a high frequency (f=39) of positive comments relating to the Bridge21 workshop. It is clear that students have engagement challenges to learning content from a book which is more passive but appeared to enjoy the variety of activity and microworld used in the Bridge21 workshop.

'Like with that Ohm thing, I learned that in five minutes. But in school I couldn't even remember it from the book. Because it showed you exactly what was going on with the computer'

'It was better than learning out of a text book, yeah.'

'Yeah. It made it easier to understand when you are actually doing it hands on then doing it from a book. It is just easier to see what you are doing [unintelligible] book.'

Participants also held negative views of physics prior to the workshop which may have lowered their pre questionnaire mean score for affective engagement. During the workshop introductions many participants indicated that they weren't enthusiastic knowing that it would focus on physics.

'I didn't like it and I felt really boring, and I was afraid it was going to be really bad today'.

'I have always hated part of all the science of circuits and stuff and I actually enjoyed what I was doing today.'

The improvement in affective engagement can be attributed to both the use of simulations and the structure of the workshop. Participants indicated that the simulations made the content more real and easier to understand. During the focus groups participants often referred to the ability to 'do things' as a positive contributor to their engagement. This aspect is captured as a subset of the three open coding themes - ***Engagement***, ***Experimenting*** *and* ***Construction Features***.

'Using the simulations as well. Like having, not a book. Because when you are looking at a book I just feel like nothing really is going in. Like you are just reading going 'right, this is pointless'. But then doing it, actually doing it yourself, using your brain and your hands to actually do [unintelligible] looking at it and its better than just looking at a piece of text that is not really explaining it just kind of saying what it is.'

5.4.2 Behavioural Engagement (BE)

Behavioural engagement (BE) showed the 4th most significant change in the MTAS subcategories (t=2.513) post the Bridge21 workshop. Behavioural engagement relates to how the students participate in the activity, their level of perseverance, ability to concentrate and willingness to challenge any prior conceptual understanding they may have had.

This improvement, as well as being statistically significant, is also supported by the focus group feedback. Through the Directed and Open coding process of the focus group data three potential reasons are proposed for this improved behavioural engagement.

1. ***Collaboration/Group Activity:***

The Bridge21worshop learning model is based around collaboration and team activities. At the start of each workshops students did an icebreaker activity in larger groups (4-5 per group) and then worked in groups of two for the problem based activities using the microworld. From observation during the workshops there was a high level of cooperation and communication between team members. When something did not work as planned with a circuit design or was in conflict with their prior understanding they would discuss and develop solutions. The layout of the workshop space meant that teams were close to each other and the researcher frequently observed teams interacting and sharing their approaches and ideas. The small group sizes also compelled participants to stay involved and contribute.

> *'I think like, when you found the problem and you solved it and the light came on and— —it worked, and you got passed the problem as a team and you had a working circuit then, I think that was the best bit.'*

> *'Whereas groups of two it's kind of— —[continues] it is a lot more interactive. And everyone has their own bit of work to do.'*

> *'You have to be involved'*

2. ***Experimenting with Simulations:***

The affordances of the PhET microworld technology allowed students to experiment with unusual designs, quickly take measurements, make changes and add in additional components. Through experimentation they created many discrepant events which challenged them and helped with their conceptual understanding of the model. From the saved circuit construction outputs from each group it is evident that many different designs and approaches to the problem were taken. Some students made an initial proposal for the Christmas tree lights problem but after further thought they tried another approach – e.g. changing from series to parallel design.

'I think trial and error was good. Like, in the software you were able to try things and if it didn't work, you'd say 'well that doesn't work—that will work—that will do it'

'Because we were actually able to see how a circuit gets put together. And we done a lot of experimentation as well. You know and, I suppose you can be told how something works but unless you, kind of, try it yourself and try different ways of doing things you don't really learn much'

'It is easier if you have it on the computer and you can put as many as you want in, because you understand it more'

3. Self-Discovery:

As highlighted earlier students held very negative views on current teaching methods in their schools which emphasised rote learning and teacher centred activities. Bridge21 encourages guided discovery with limited intervention by the support teacher. During the workshops participants were only provided with information sheets on the problem and an outline of guided activities to support use of the microworld. They were not told 'how' to do the task but rather could create their own approach and seek assistance from the teacher as needed. From this researcher's observation, students either tried one approach and made adjustments as needed or sought to discuss an idea/ approach with other teams. This interaction was easily facilitated by the layout of the workshop environment and by the flexibility of the simulation technology to adapt and give immediate feedback.

'It is easier to create it yourself, rather than it is to have look at it in a book.'

'Because you got to work with it yourself, instead of someone just sitting up at the board explaining to you.'

'Instead of being shown how to do it you figured it out for yourself.'

'Because it wasn't like school. It was like, I don't know—because you didn't tell us we have to do this, and then this and then this. We got to just learn how to do it ourselves, kind of. And it makes you understand it more and it is more fun than just being told what to do.'

5.4.3 Confidence in Physics (PC)

Statistically the change in the students' Confidence in Physics (t value=3.36) was the 3rd most significant of the MTAS subscales post the workshop. It is clear that prior to the workshop many students considered physics to be difficult with a high dependency on their mathematical capability. This perception linking physics ability to mathematical capability may have led to the pre questionnaire mean score (mean=12.50) being the lowest for all the MTAS subscales. The directed coding of the focus group data exhibited the second highest frequency of comments against this subscale (Figure 5-1). These opinions may be reinforced by the fact that many teachers approach physics from a mathematical perspective without first developing real world connections and facilitating conceptual understanding.

> *'One of the exams I remember doing, I realised that physics requires a lot of maths. And if you weren't really that good at maths you could have failed it.'*

> *'It relies a lot on maths and stuff and I am not exactly the best at maths. But I feel like I could get a better grasp of it today.'*

> *'It was, seemed a lot more difficult when you view it just being another maths subject. Because if you are not good at maths you think you won't be any good at physics.'*

The change in confidence post workshop can be attributed to contextualised learning of the workshop and the fact that students could relate it to real world situations and the mathematical formulae were scaffolded in the learning activity to aid problem solving. Students enjoyed the problem related to designing Christmas tree lights and calculating the total resistors in series and parallel.

> *'Maybe, because I have a little bit more of an understanding of how it works and stuff like that.'*

> *'The equations are a lot more easier now. Now that we have actually put them into practice.'*

> *'I thought it was maths before, but it is not all maths'*

> *'It would make me want to do physics when I leave.'*

5.4.4 Technology Confidence (TC)

The only MTAS subscale that did not show any significant improvement (t value =1.275) between pre and post workshop was a student's Technology Confidence. This is not surprising given the pervasive use of smartphones and social media by this age group of students and would suggest they are comfortable with technology and how to use it for their benefit. The mean pre workshop score for this subscale (TC Pre Mean = 14.3) was relatively high when compared to some other MTAS categories. Very little intervention or explanation was required during the workshops and students quickly figured out the features and functions of the simulation tools.

> *'It was basic enough to understand. Even if you were computer illiterate, it would still work.'*

> *'Yeah, they were just simple. They were really simple but explain like a lot.'*

5.4.5 Attitudes to Using Technology to learn Physics (PT)

This MTAS subcategory showed the most significant change in attitude post the workshop and resulted in a t value (t=6.894) that was almost twice that of the next most significant of the subscales. Given the high mean value of 17.0263 for the post workshop questionnaire (Table 5-1) it is plausible to suggest this significant impact is due to the workshop itself and not contributed to by any prior negative experiences. This improvement in attitude is also supported by the directed coding of the focus groups. From Figure 5-1, PT had the highest coding frequency (ε3 f=59) for positive attitude to the physics workshop. The focus groups and open ended questions provided good insight into what aspects of the simulations the participants found beneficial.

1. ***Visualisation*** – the ability to see what was happening and to observe abstract concepts such as electron flow and capacitor charge. This supported participants' conceptual understanding of the physical phenomenon and through this researcher's observation, also helped in connecting this with the mathematical representation.

   > *'But it was cool to be able to see 'well that is not working, what I can do to change that?' And then you knew what you were doing as opposed to someone adding something in and you just watching. Like when you added a resistor or something like 'oh that works'.'*

   > *'I didn't know that electricity was the flow of electrons. [You could see the way that they were going around]. So that was good.'*

2. ***Experimentation*** – students enjoyed making the circuits and trying out new models. They mentioned that they could quickly see if something worked or not and that there were no dangerous consequences of making mistakes. This compares with the cautious experience they have with lab experiments in their schools.

'I think trial and error was good. Like, in the software you were able to try things and if it didn't work, you'd say 'well that doesn't work—that will work—that will do it'.'

3. ***Construction ('Doing')*** – a recurring theme during the focus groups was related to being able to 'do things'. With the freedom to create, students developed their own models and views of the circuits they constructed. Since the PhET software is based on real electrical principles students often created circuits that did not work or because of voltage irregularities went on 'fire'. This challenged students to understand what was happening and propose a solution.

'I think we only got the hang of it today. It helped. Yeah, just using those things helped a lot—the computer and stuff.'

'And doing things in a more interactive, and like hands on way. People rather it, and they start learning things a lot easier when they do it hands on.'

One student mentioned the immediacy of the feedback from the simulations. They knew instantly if it worked or not.

'It was nice to have a definite answer at the end of it. Like, it wasn't going to be something that you weren't sure about. If the light was on, you did it right. If it wasn't, you did it wrong. It is nice to know that you did it right or wrong.'

Students also mentioned the challenges they face in their own schools around access to materials for experiments. It is difficult to get sufficient supplies for electrical experiments and often the items do not work.

'And like even when you do get to do the experiments—like say if we were doing one, electricity and stuff like that, a lot of the stuff in school you would have to fight to get good ones that aren't broken and stuff.'

5.4.6 Bridge21 Model

As part of the Directed Coding exercise two further themes were searched for in addition to the 5 MTAS subcategories. These were Bridge21 and Lesson Design. Coding against Bridge21 helped understand the impact of the specific learning model used for the workshop and what attributes the participants considered beneficial. As mentioned earlier students had quite negative views of their current school teaching methods and the workshops incorporated many aspects missing in their schools. Bridge21's focus on collaboration and the contextualised learning was viewed very positively by participants and was in contrast to the negative views about their schools. Bridge21 also encourages guided discovery and puts the students own discovery and investigation at the centre of the process. Participants clearly valued the freedom to direct their learning and this may have contributed to the higher level of engagement recorded post workshop.

> *'Yeah. I think (it) brought people out more. And everyone expressed their opinions because it was just two people'.*
>
> *'It's bit more enjoyable to learn like this. It sticks in your head more.*
>
> *'Like today was very practical, we got to see why things worked.'*
>
> *'Also, like I didn't feel like was actually doing work. I felt like that was just the little mini game on the computer screen and I was kind of playing it. But learning as well as I was working'*
>
> *'Yeah, I just viewed it as a school subject. But after the workshop you see it is a lot more real-world stuff. '*

Another important aspect of the Bridge21 model is student reflection and group presentations. From the researcher's observations and reviewing student PowerPoint presentations slides after the workshops it was evident that this process consolidated a student's conceptual understanding of the subject area. It also allowed students to learn from different perspectives and from other groups. For example during the presentation of one group they showed a circuit they had created with 'flames' (due to voltage overloading) at various points. They discussed potential reasons for it and how they might mitigate it in a future design. Through the process of sharing this discrepant event the whole group benefited. Samples of student output are shown in Appendix B.

5.4.7 Lesson Design

An important consideration when designing the workshop activity was how best to scaffold the learning for the participants. The majority of the 39 participants had studied science to Junior Certificate level and had very limited knowledge of electrical circuits. The physics workshop was introducing many new concepts in a short time frame. During the second workshop many participants found it difficult understand the concept of series and parallel circuits and were also very confused by the mathematical equations underlining the models. The researcher decided to intervene and explain the formula but this only further confused the students and adjustments need to be made to the next day's workshop.

> *'Yeah, there were so many confusing bits.'*
>
> *'When you start talking on that board, I just zoned out.'*

Based on discussion and feedback from a secondary school physics teacher who observed one of the workshops it was decided to be more deliberate in scaffolding during the early parts of the workshop, when new concepts were being introduced.

At the start of these later workshops students were required to recall and present what they already knew about physics, electricity and circuit design. This helped build a student's confidence that they would be able to contribute during the workshop. Before students were provided access to the PhET Circuit Construction microworld they were given two short PhET simulations which explained Ohms Law and resistance, two important theories that would scaffold their understanding. They worked in groups on these supplementary simulations and were asked present their findings to the full group. This clarified concepts for the students and helped improve their use of the PhET Circuit Construction Kit microworld.

From the focus group output many comments relating to the workshop lesson design were coded. These comments were mainly suggestions on what participants thought could be improved. Two main recommendations were identified

1. ***Length of the Workshop*** – participants indicated that the workshops, at approximately 5hrs duration, were too short. They felt the time went quickly and they could have done with more time to prepare presentation feedback on their circuit design.

    'Bit longer! Okay. We felt it was a bit short'

    'Yeah, it was a little bit short. Just like coming to the first lunch just seemed very quick. The same with the rest of the day.'

2. ***Variety of Subject Matter-*** due to the limited choice of available simulations with a high construction capability the workshops addressed only electricity and circuit construction. Participants clearly indicated that they would like to cover other physics topics in a similar way.

    'Ehm, maybe an extra day or two and other topics. Like physics but other topics in physics not just electricity.'

    'We could have done a bit more, instead of just sticking on the circuits for half the day, move onto something else. Like besides those circuits. Like move onto heat and stuff like that.'

    Interestingly one participant mentioned they would like to see additional features and capabilities built into the circuit construction kit software. They wanted to explore more electrical components and create more complex, sophisticated circuit designs. Although the PhET software had ability to add capacitors, AC current and other components, due to short time frame the workshops focus was on resistance theory.

'Um, I suppose if we did more different angles of the same kind of thing. We could do a lot on the circuit simulator but there was still only a few different circuit components. You know if there was more kind of different circuits that we could try and make.'

5.5 Summary

The findings resulting from the analysis of the data gathered through mixed method data collections provide clear evidence to answer the questions posed by the research. The MTAS questionnaire showed statistically significant differences across 4 of the 5 subscales between pre and post activity questionnaires. Attitude to use of technology to teach physics (PT) showed the largest statistical gain followed by Affective Engagement (AE), Physics Confidence (PC) and Behavioural Engagement (BE) in that order. The paired t-test results were significant across all four measured results. The results of directed coding of the focus group data against the MTAS subscales also aligns well with the quantitative data. The frequency of occurrence of the open coding themes was highest for a positive reaction to the physics workshop for PT, PC, AE and BE, again in that order. This matches the order of the measured impact from the MTAS data. Two further directed coding categories (Bridge21 and Lesson Design) were used and these again resulted in a high frequency of responses against a positive reaction to the workshop.

The qualitative data also pointed to the reasons for the positive changes in Engagement and Confidence in physics arising from the combination of the microworlds with the Bridge21 pedagogy. These included Collaboration, Experimentation, Self-discovery, Visualisation and Construction activities. The data also provided recommendations for improvements to the lesson design such as more variety of physics topics and a longer duration to the workshop.

Chapter 6: Conclusions

6.1 Introduction

This dissertation has successfully addressed the main research questions posed at the outset of this investigation. It has described how a highly immersive, construction enabled microworld, when combined with a 21st century learning model can positively impact student engagement and confidence in physics. Statistically significant improvements have been observed in four key areas - affective engagement, behavioural engagement, confidence in physics and attitudes to use of technology to learn physics. This chapter considers potential limitations of the research specifically around the narrow focus of the physics topic used and also the influence volunteer participants may have. The study has identified several areas worthy of further research and investigation. Three suggested areas are discussed in this chapter – Maths v's Physics conflict, gender differences and how to implement microworlds in conventional classrooms.

6.2 Summary Research Findings

The primary research question answered from this research is

- How do microworlds, when used as part of a 21st century learning model, impact student engagement and confidence in physics?

This question is addressing a potential solution to the declining interest and engagement of students in physics at secondary level. The results of this case study have shown a positive and statistically significant impact and this is also supported by qualitative student feedback.

Additional sub questions were also considered during the study

- Do microworlds impact students' attitudes to learning physics with technology?
- What factors need to be considered if microworlds are to be integrated into conventional classroom environments?

6.3 Engagement Impact

This research has clearly demonstrated that microworlds, when combined with a 21st century learning model have a statistically significant impact on both affective and behavioural engagement in students. Students found the Bridge21 workshop enjoyable and fun. This is in contrast to their views on their schools' didactic teaching methods leading to physics being considered as boring and not related to real world situations.

The research identified several factors that contributed to the increase in behavioural (BE) and affective engagement (AE). These are

- Microworld Technology
- Collaboration
- Self-Discovery

The construction capability of the PhET microworld was a significant factor in the improvement of participants' affective engagement. It is possible that a contributing factor to this impact was the novelty factor of the workshop, being so different from their conventional classes. However when the increase in behavioural engagement is also taken into account, where the level of concentration and conceptual understanding of students also increased it is more probable that the microworld technology contributed more strongly to engagement levels. Behavioural Engagement is a deeper level of engagement as it considers how motivated students are to learn and how actively they participate in learning process. The PhET microworld allowed students to create their own models and use these to confirm or challenge their understanding of the underlying concepts. The PhET microworld also enabled students to see and understand abstract concepts such as electron flows, capacitor charges and this is something they cannot easily grasp through textbooks or real physical experimentation.

The importance of the collaboration during the Bridge21 workshop where students worked in teams, discussed their solutions and were asked to present back to the whole group is also evident from the qualitative data.

The Bridge21 workshops emphasise learning through discovery and the teacher taking on the role of facilitator. Allowing the students freedom to explore within the microworld was important contributor to impacting both types of engagement.

6.4 Impact on Confidence in Physics

The research findings has provided clear statistical evidence that these workshops made a significant improvement in the students' attitudes to physics and to their confidence with the subject. Through a structured analysis of the qualitative data 2 main areas that contribute to this are

- Bridge21 (when contrasted with their conventional class experience)
- Contextualised learning

The contrast of the Bridge21 model with their own class experience was very evident from the workshop focus groups. Students' confidence in physics prior to the workshop was coming from a low base largely driven by what they perceived as poor lesson structure and design in their schools. Learning physics from a text book makes it boring and difficult to understand concepts. Students also expressed that they had limited time and resources in their schools to conduct experiments. One recurring theme is the belief instilled in students that they need to be good at maths to be good at physics. This is often reinforced by teachers and fellow students but also by teaching mathematical formula rather than relating concepts to real world situations. The researcher calls this the ***Maths v's Physics Conflict*** and is a strong factor contributing to a student's low confidence in physics.

By contextualising the learning of physics to real life situations (Christmas Tree lights, car lights problem) during the Bridge21 workshops students had a basis from which to understand the concepts and then apply the underlying mathematics to solve the problem. Contextualised learning is a key element of the Bridge21 model and contributed to the improvement in student engagement and conceptual understanding.

6.5 Technology Effectiveness

With a t value =6.894, student attitudes to using technology in physics learning (PT) showed the most statistically significant change as a result of the Bridge21 workshop. The choice of microworld technology was a major factor in this improvement. The data suggests several features of the PhET microworld that led to this dramatic change

- Visualisation
- Experimentation
- Construction Capabilities

Considering the **SAMR** (*Substitution, Augmentation, Modification and Redefinition*) framework discussed in the literature review these features of the microworld technology place it in the redefinition category of the model. The microworld is allowing students to do, imagine and create new models in ways that is not possible with existing teaching methods or through technology substitution or augmentation. The evidence from the research findings indicates that redefining the use of technology was an important contributor to the impact on student engagement and confidence in physics.

6.6 Integrating Microworlds into Conventional Classrooms

An outcome of this research investigation was to understand what scaffolding considerations needed to be taken into account when integrating the simulations into a 21st century learning environment. The ease of use, high construction and interactive capabilities of the PhET microworld meant that students could experiment and benefit from self-discovery and thus require limited scaffolding. An important scaffolding requirement identified during the research was to use supplementary PhET simulations at the start of the workshop that addressed gaps in participant's knowledge. If this scaffolding is not provided students will 'play' in a non-directed way with the Circuit Construction Kit and become confused as to the purpose of what they are trying to do. Behavioural engagement will be affected when they encounter challenges as they will not have the conceptual understanding to overcome these.

Considering the positive findings from the Bridge21 workshops and the negative views participants expressed about their own school teaching methods, the question of how this model could be integrated in to a conventional school classroom needs to be considered. The timeframe and scope of the research did not allow for this question to be studied in detail but the findings point to some important considerations.

1. Guided Discovery & role of the Teacher

When implementing in a school classroom, emphasis should be on guided discovery through problem based activities. The role of the teacher will change to facilitating the activity and only intervening when required. For this model to be successful, teachers will need to be supported in appropriate techniques and give greater freedom to the students to arrive at their own, alternate view of the problem.

2. Physical environment & equipment

A key consideration to implementing the model in schools is the access to enough good quality computer equipment. From this study having 2 people per station was optimum. Schools will need to design a flexible workspace where teams can come together for presentations and where exchange of ideas and collaboration can occur between work teams.

3. Class time allocation

The typical 40 minute class time in secondary schools would not allow for the implementation of the proposed model from this research. The Bridge21workshops were typically 5 hours in duration. This allowed learning to be appropriately scaffolded, to incorporate problem based activities and time for students to experiment with their circuit designs.

6.7 Limitations of the Work

- **Examined a single Physics topic area**

The research focused on the topic of electricity and circuit design. One of the main reasons for narrowing to this area was the availability of microworlds with high construction capabilities. The research findings would be more conclusive if the same level of impact was measured using other simulations and addressing other abstract physics topics such as quantum physics or atomic physics. These are often difficult concepts for students to grasp and may have pointed to other microworld features and differences in scaffolding required.

- **Timing of focus groups – lack of secondary follow up**

All the focus groups were held immediately after the Bridge21 workshop was complete. This yielded fresh opinions from students about the workshop and how it contrasted to their own school environment. The researcher believes that having a second follow up with participants would be beneficial. This would allow them time to more fully reflect on the workshop and possibly give richer suggestions on what could be improved. It would also support discussion about how the activity could be integrated as part of their school classes.

- **Quality of questioning during the focus groups**

As this researcher was reviewing the focus group transcripts and coding the data there were many occasions that a follow up or clarification question should have been asked. This was due to the inexperience of the researcher at hosting focus groups, particularly with 15-16 year olds who did not always articulate their opinions clearly. The interviewer missed some key opportunities to clarify and explore more fully the points raised.

- **Volunteer Participants**

All participants in the study were self-selecting volunteers and had the opportunity to attend Bridge21 for the day instead of attending their own classes. The opportunity to meet students from other schools and novelty of the Bridge21 activities could be a contributing factor to the increase in some of the MTAS subscales.

6.8 Recommendations for Future Work

- **Investigate Maths v Physics conflict**

A view that was prevalent among the participants was that to be good at physics one needed to be good at mathematics. This view had a significant impact on their confidence in physics even though the majority (69%) of participant's were taking higher level maths for the Leaving Certificate. It would be important to understand more fully the reasons for this and its impact. The ability to apply mathematics is important in physics problem solving and further research could investigate the application of technology and appropriate scaffolding to improve this capability in physics students.

- **How to incorporate into a typical school classroom**

The Bridge21 workshop was an out of school activity. Further research is required into how this model can be incorporated into a school environment, where didactic teaching practices are prevalent and where schools are constrained to teaching curriculum for state examinations.

- **Gender mix**

41% of the participants were female and only 12% of these girls were planning to do Physics for the Leaving Certificate. This compares with 34% of the boys who indicated they would continue to study physics. Time did not permit the researcher to use the data to compare pre and post workshop MTAS results based on gender. This is worthy of further investigation to understand which gender group might benefit more. It may also indicate differences in how the activity should be scaffolded for either group.

6.9 Summary

This case study has provided a rich set of findings and answered the primary research questions posed at the outset of this investigation. It has shown that microworlds, when combined within 21st century pedagogy, will significantly increase student engagement and confidence in physics.

In summary the contribution of the research is

- The successful integration of construction enabled microworld with a 21st century learning model to impact student engagement and interest in physics.

- Results from an exploratory case study which show a statistically significant impact to participant's levels of Affective Engagement, Behavioural Engagement, Confidence in Physics and their Attitude to use of technology to learn physics.

- Recommendations on how to scaffold the use of microworlds in a 21^{st} century learning activity.

'But how can you really make physics more fun, but you did it there.'

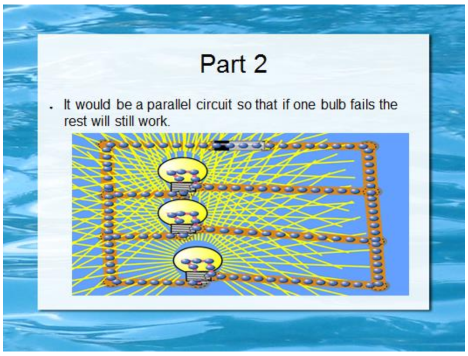
Appendix A Bridge21 Workshop Structure

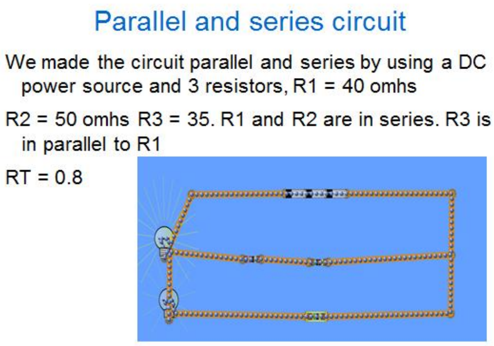
Flow and timings used during the workshop. The Icebreaker and warm up activity are important steps to help facilitate student engagement and team collaboration. Focus group sessions were held immediately after the workshop concluded.

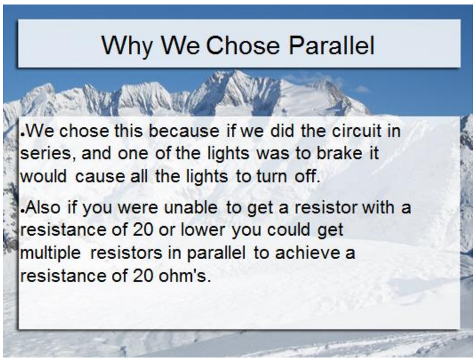
Activity Flow	Time (Hrs)
• Welcome & Introduction to the Day -collect consent forms	10.00
• Pre-questionnaire – assess students prior understanding & level of engagement	10.05
• Ice Breaker Activity & Team formation	10.15
• Warm Up – Discussion on what they know about Electricity & Circuit Design -raise some conceptual questions -what if style questions -introduce ***Resistance*** and ***Ohms Law*** simulations -Short team presentation - explain day's learning activity & objectives	10.25
• ***Microworld: Circuit Construction Kit*** - 30mins -Allow guided play time and initial exploration -Share activity guide - cover series parallel circuits, resistance	10.35
• Discussion on findings & questions raised by simulations -present back on measurements and conclusions	11.05
• Break (10mins)	11.15
• Problem Based Activity - Build a circuit problem - specific guidelines on what is expected,	11.25
• Prepare presentation on findings, observations & conclusions - Methodology used , Observations,	12.10
• Lunch	12.40
• Students present back to full group on their approach and findings	13.15
• Post activity questionnaire	13.35
• Focus group interview -What did you think of activity, hardest aspect, did you learn etc. -Break out by specific task	13.45
• Finish	14.15

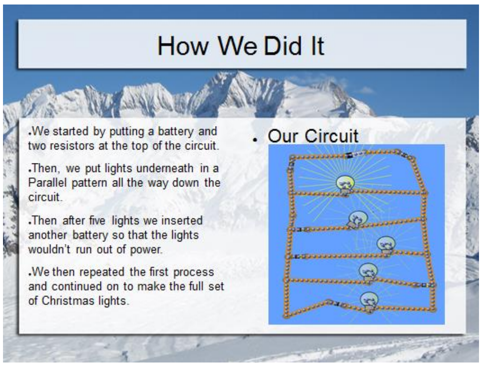
Appendix B Output from Student Presentations

Students presented back to the whole group their findings and conclusions to the problem based activity. Presentations were done using Microsoft PowerPoint and students also used saved or live versions of their constructions from the PhET Circuit Construction kit.

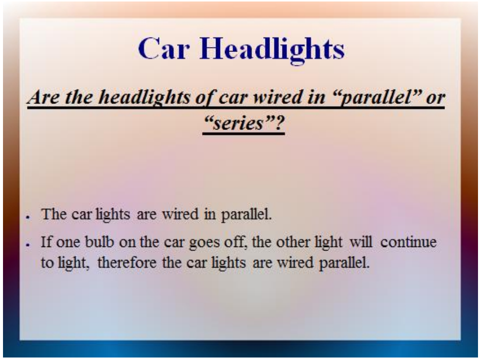








More resistance smaller wire
More current bigger voltage
Wider wire less resistance
More voltage more current
More resistance less current
Less resistance bigger current



Appendix C MTAS Questionnaire

The 20 question modified MTAS questionnaire used for gathering quantitative data pre and post the Bridge21 workshops.

Q5: Considering your experience at today's workshop please rate the statements below against the rating scale in the table.

No.	Statement	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
1	I concentrate hard in physics					
2	I try to answer questions the teacher asks					
3	If I make mistakes, I work until I have corrected them.					
4	If I can't do a problem, I keep trying different ideas.					
5	I am good at using computers					
6	I am good at using things like smartphones, tablets and apps					
7	I can fix a lot of computer problems					
8	I can master any computer program needed for school					
9	I have a PHYSICS mind					
10	I can get good results in physics					
11	I know I can handle difficulties in physics					
12	I am confident with physics					
13	I am interested to learn new things in physics					
14	In physics you get rewards for your effort					
15	Learning physics is enjoyable					
16	I get a sense of satisfaction when I solve physics problems					
17	I like using simulations for physics					
18	Using simulations in physics is worth the extra effort					
19	Physics is more interesting when using simulations.					
20	Simulations help me learn physics better					

Appendix D MTAS Pre & Post Questionnaire Data

The responses from each student to the MTAS questionnaire were scored on a scale of 1 -5. The scores for each student, across each of the 5 MTAS subcategories, pre and post workshop were imported to Microsoft Excel for further analysis.

Student #11 did not answer the pre questionnaire (zero score) and this student data was removed from subsequent analysis.

Student #	BE Pre	BE Post	TC Pre	TC Post	AE Pre	AE Post	PC Pre	PC Post	PT Pre	PT Post
1	13	12	16	16	12	12	12	12	12	16
2	14	14	13	12	15	16	13	15	16	16
3	16	16	13	16	14	13	16	15	12	14
4	14	15	12	9	18	17	8	10	12	16
5	12	16	17	15	16	16	11	12	13	14
6	11	15	14	14	10	11	10	11	12	16
7	14	17	16	15	12	15	9	13	12	20
8	16	15	10	8	15	15	13	14	13	15
9	15	15	7	7	17	19	13	13	12	17
10	20	20	20	20	20	20	20	20	19	19
11	0	16	0	13	0	14	0	10	0	12
12	16	16	20	20	18	18	14	13	15	20
13	16	16	16	16	17	16	15	15	12	16
14	11	14	12	14	12	12	6	11	12	16
15	17	18	19	19	15	18	18	16	17	19
16	16	16	12	15	8	14	4	9	4	20
17	14	11	13	13	10	17	4	11	12	20
18	16	15	16	16	20	20	20	20	19	16
19	20	20	17	19	16	17	18	17	12	15
20	18	17	17	16	17	16	14	14	16	19
21	18	19	18	16	16	15	19	17	14	19
22	16	16	13	14	11	8	13	12	11	12
23	15	14	13	13	16	16	16	17	16	20
24	16	20	15	20	19	20	15	20	12	20
25	16	16	15	14	17	16	14	15	13	12
26	14	13	9	11	14	16	11	11	12	15
27	11	12	15	15	15	17	8	12	14	20
28	14	14	16	17	16	17	11	13	12	19
29	15	16	14	11	13	14	8	9	12	12
30	18	17	10	14	16	18	13	15	10	19
31	16	17	18	18	20	20	19	20	20	20
32	11	15	12	14	16	16	8	12	15	20
33	16	17	15	17	14	17	11	13	11	20
34	6	9	11	13	7	9	6	4	6	12
35	15	16	14	17	15	17	13	14	12	18
36	15	16	9	13	15	16	16	15	15	16
37	15	16	20	16	9	15	14	15	14	16
38	19	18	20	20	12	17	12	12	15	17
39	14	16	10	10	13	17	10	13	12	16

Appendix E Directed Coding Sample

Below is a sample page showing how the transcripts from the focus groups were reviewed and marked up for the directing coding analysis.

Conor Wickham, cwickham@tcd.ie — Day 1, Recording 1

[0:04:50]

CW: —because you could see things?

X: Because you could visually see what each thing you did— ξ3

X: —what would happen.

X: —effected and stuff like that. ξ3.

X: It's better than just learning that from a board, if anything. Because you get to do it yourself so you know what to do in future. ξ2 ξ3

X: You know where you are going wrong. ξ3

X: You get to learn what is good and what is not. Like not putting 1000 volts onto a battery and then trying to light a light bulb from it then. ξ3

X: When you make a mistake you can go back and fix it. While when you are just taking notes down you just have one example and you just have to learn that example off by heart. And if you can't remember it then—[overlapping, unintelligible] ξ3 ξ2

X: Then it can be hard to change the situation using just that one example. ξ2

X: And if you did that in real life the [unintelligible] could go wrong, and something would go terribly wrong and— ξ2

[laughing]

—from a computer you could just fix it easily—but if that happened, you would have to start from scratch. ξ3

CW: Yeah.

X: [unintelligible] start from scratch.

X: [unintelligible]

CW: So before you came into today I was asking you about physics and a lot of you said that you were doing biology or chemistry or going to pick that. What was your impression of physics before you came in today?

X: I think it is not taught very well in our school. α2.

X: They kind of, they—when I was in science, they left physics—every year, they left it until the very very end of the year. α2

[0:09:15]

157 X: I am leaning a bit towards physics now. $\partial 3$

158 X: [unintelligible]

159 X: Anything else you want to add before I hit the stop button?

160 X: Not really.

161 X: It was a good experience. $\alpha 3$

162 X: Don't set batteries on fire.

163 [laughing]

164 [Thanks and interview ends [00:09:39]]

$\alpha 1$ – 0
$\alpha 2$ – 10
$\alpha 3$ – 7
$\alpha 4$ – 0

$\beta 1$ – 0
$\beta 2$ – 0
$\beta 3$ – 0
$\beta 4$ – 0

γ_1 – 0
γ_2 – 0
γ_3 – 0
γ_4 – 0

$\partial 1$ – 0
∂_2 – 5

$\varepsilon 1$ – 0
$\varepsilon 2$ – 14
$\varepsilon 3$ – 17
$\varepsilon 4$ – 0

ϕ_1 – 0
ϕ_2 – 0
ϕ_3 – 0
ϕ_4 – 0

κ_1 – 0
κ_2 – 0
κ_3 – 0
κ_4 – 3

Appendix F Open Coding Sample

Below is a sample page showing how the transcripts from the focus groups were reviewed and marked up for the open coding analysis. Themes emerge during the initial process and are then grouped for final analysis.

Conor Wickham, cwickham@tcd.ie -interview/focus group details

'NewRecording Workshop Group2'
date

Conor Wickham: So what we want to do is just try and get a little bit of feedback from you. [0:00:01]

X: Alright.

CW: —just on today and your experiences of today.

X: [unintelligible]

CW: —and what you thought.

[all laugh]]

CW: So maybe, what did you think of today? Did you enjoy it—

X: Yeah. I thought it was good. It was more fun than using books, which I really enjoyed because I don't really like using books. I prefer doing stuff.

CW: Mmm-hmm. Good.

X: Yeah.

[all laugh]

X: I felt it was nice using all this stuff on the computer. And it was just easier. You get to kind of see it for yourself and see where you went wrong. And you can correct your mistakes easily on the computer. And then it is easier. Rather than drawing it, where you would have to like rub it out and redraw it again, it is nice because it is like delete it and then [just do another line].

X: Also, like I didn't feel like was actually doing work. I felt like that was just the little mini game on the computer screen and I was kind of playing it. But learning as well as I was working [unintelligible].

KS: [overlapping] A puzzle to solve rather than—

X: Yeah, actual [homework] or an assignment, yeah.

X: Yeah. It made it easier to understand when you are actually doing it hands on then doing it from a book. It is just easier to see what you are doing [unintelligible] book.

CW: And how does—when you studied science in, up to Transition Year, what was the—or up to Junior Cert.—what was the structure of your class and how did you learn—

Appendix G Focus Group Transcript Sample

Sample of a full focus group transcript recorded from Workshop #4, January 28th 2015.

Day 3, Recording 2.

Conor Wickham: So we have the second group on day three and the purpose of this is just to get your feedback and input on how today went, what you thought about how we could improve it and so on. So let me just ask a general one, how was today? What did you think of today? What were the good things about today that you liked? [0:00:02]

[laughing]

Your first thoughts?

X: It was good. We got to meet new friends. Of course, from an all boys school we got to hang out with girls—

[laughing]

–well it is not that we don't hang out with girls, it is just that you know—we are not that lonely—

[laughing]

—I got to learn new stuff. Well like stuff.

CW: What new stuff?

X: Stuff that I need for technology, because I am going to be keeping it, and I did it for third year as well. So that is going to help me as well when I get to fifth year. And some of the things in the circuits I didn't really understand back then, in the Junior Cert because some teachers don't really explain it properly. But you know I kind of get it now, I understand it more now.

CW: Good! How does everybody else feel? What did you like about today?

X: It was fun. I thought like, I think physics is really really hard, but then doing like if you think about what is in front of you more, it makes it easier.

CW: And what was it about today that made it fun?

X: Because it wasn't like school. It was like, I don't know—because you didn't tell us we have to do this, and then this and then this. We got to just learn how to do it ourselves, kind of. And it makes you understand it more and it is more fun than just being told what to do.

CW: Good. Anybody else?

X: Using the simulations as well. Like having, not a book. Because when you are looking at a book I just feel like nothing really is going in. Like you are just reading going 'right, this is pointless'. But then doing it, actually doing it yourself, using your brain and your hands to actually do [unintelligible] looking at it and its better than just looking at a piece of text that is not really explaining it just kind of saying what it is.

CW: Good. And what was it about the simulations that you liked? Tell me what you thought of the simulations.

[0:02:12]

X: I thought well, they were pretty easy to use. I don't know about anyone else, but I thought anyways. And they just like explained it really well—

[laughing]

—I will let you talk. I will let you talk now go on.

CW: You will all have time to give input so just [unintelligible].

X: —Yeah, they were just simple. They were really simple but explain like a lot. Say you would use [ten pages] from a text book but this was just like one programme, explaining a lot of information. For me anyways. Because I wasn't really good at physics and maths—

CW: And why do you think the simulations helped you understand? What was it about them that—what aspects of it did you like?

[pause, silence]

Anybody else want to add—

X: [overlapping, unintelligible]

[laughing]

X: —I don't really—It is kind of hard to explain it, like what—I just think like they were a lot easier, they were just *easy* to do. Like looking at something and like—

X: They are just so simple, and yet you could learn a lot from them—

X: —there is nothing complicated about [doing] something and like this is how this works—

X: —yeah—

X: —and it is not like—like this is how your *real* life works, if you get me.

CW: Okay so the real life bit was good.

X: Yeah.

X: It was easier seeing how it is done, than just reading and trying to figure out what would happen like. So you are just seeing how they all go together and trial and error and all—

X: Yeah it is just like—

CW: Okay so the trial and error obviously you can—

[general agreement]

X: —it is like instead of just reading and like 'ah, yeah' and then you go over to your friend—

X: [overlapping] If I do this, this happens.

X: —you will probably get it wrong three or four times. But doing that it doesn't matter, you are not wasting anything. You are doing it on the computer like. [0:03:30]

X: Yeah and, me I have already done [unintelligible] so I kind of understand already, but for them even though they didn't really do technology—or that is what she told me anyways—they still could of understood it. So, which kind of means it wasn't that difficult.

CW: Tell me a little bit about classes of science or technology today in school. How is it organised and structured? What type of things do—

X: In fourth year or—

CW: Well, third or fourth year, whatever you are doing at the moment just in your school. Is it, do you do a lot of experiments, do you—

[general disagreement]

—do you use text books.

X: Yeah, we do experiments every double class we have.

X: We don't—

X: We don't—

X: Our teacher just rambles on [while he stands at the front]—

X: —yeah and then just gives us questions to do after that.

X: —You could be doing the same questions three days in a row.

X: Oh, right! Oh.

X: We actually could.

[aside, unintelligible]

X: And sometimes they don't even correct it, so.

X: Yeah, he just talks about one subject and then he just goes on to another. And a lot of people start falling asleep. Yeah that's me!

[laughing]

CW: So what do you think you learned today? What do you think the purpose of today was by the way? What do you think we were trying to achieve?

X: [unintelligible] physics.

CW: Yeah.

X: To get people more interested in it, that there is a fun side of physics.

X: To show the interesting side of physics to get people more interested in it. [0:04:51]

X: To show that it is not that hard because physics in known as the hardest—

X: Yeah.

X: —because like at our school, sometimes it is not even an option to do physics because not enough people like pick it because it is so hard.

X: Yeah.

X: I think chemistry is harder.

X: Yeah.

X: Well people—

X: In our school there is only—what ten people are in the physics class. Probably because everyone picked biology because thought it is easier.

X: Yeah normally people would see it as a hard subject.

X: I am choosing physics, so.

X: Everyone picks biology or chemistry because they think physics is going to be harder. But it is not really.

X: You would have to know the theory of things.

X: The theory, yeah. Because it is not like remembering things, it is like knowing how to do it.

X: It depends on what kind of things [unintelligible, overlapping].

X: I learned that if you show interest in it, you find it a bit easier.

X: And if you show different ways, they'll learn. Not just text, using programmes and even games and stuff.

CW: Before you came in today what was your—you touched on it a little bit, what was your impression of physics? Did you have a view of it before you came in today?

X: I thought we were going to be doing really hard questions.

[laughing]

CW: Okay so you thought it was going to be hard questions. Equations?

X: Yeah. I even brought my calculator and everything.

[laughing]

And my [maths] table, I came prepared.

X: I didn't know I was going to physics. But I never really liked physics before but I like—I was honestly stupid at it. I didn't know how to do anything. And I would learn it and for ten minutes and [0:06:10] ‘yeah I know what I am doing’. And ten minutes later I would be like, ‘what do I do?’ But now it is kind of like, if I look at it again I might remember how I did it, like when we did it on the simulators [unintelligible].

CW: Okay. Any thoughts on physics before you came in here?

X: Ah, I liked it. It is like, I never really understood it fully. But now I am slightly, yeah.

CW: Yeah, good. Do you think as a result of the workshop today your confidence in physics has risen?

[general agreement]

Do you think it requires a lot of maths?

X: No.

X: No.

X: It is kind of basic maths. Just you had to use a bit.

X: It does require maths but it is not hard maths.

X: Just dividing and the multiplying thing.

X: You have to remember how to do all the different sums.

X: I think it is the hardest part is you have to know what to multiply and what ones to divide. It is part of the [overlapping, unintelligible].

X: And some of it is just about common sense as well you know.

CW: Is there anything we could improve about today? What did you not like about today and how could we improve it?

X: Make it a bit longer.

CW: Bit longer! Okay. Why felt it was a bit short?

X: Yeah.

X: Yeah. I would have liked it to go a bit longer though. [unintelligible overlapping]

X: And vary the topics as well—

X: Yeah.

X: —because we stuck to the circuit.

CW: So have a variety of different things to go through?

X: Yeah. Like, me, I was already interested in physics because I got ‘A*’ mainly in my [unintelligible] in physics so. So I was kind of [unintelligible]—but the circuit was still good. [0:07:45]

CW:	Anything we could improve on? Longer is one. Anything else we could do in the class, group?

X:	I think maybe for me, because I just kind of went into it, and you know the way we went straight into the first activity—[unintelligible] that we were looking at, like what goes up what goes down.—maybe going over a bit of the [textbook] material,. Even condense 'this stands for this and blah blah blah'. That for me, because I am not really good at physics, it was kind of like 'oh right so I am going in, just straight into proper physics'—

X:	Yeah I didn't know what the [origins] of stuff were.

X:	—A bit of even general information of what we are doing: 'oh this is this, this is that'.

X:	Yeah.

CW:	Okay.

X:	Play more games at the start.

[laughing]

X:	I thought there would be more people.

CW:	More people?

X:	I didn't mind that there was kind of a small group. But since there was a small group I think it would be better if we had an introduction first—

CW:	Okay.

X:	—just to say hi.

CW:	Do you think you got a better grasp of the concepts of physics, of the circuits by using the simulation? Do you think that helped you?

[general agreement]

So what was that do you think? Could you explain what you—

X:	I think because it was different—

X:	yeah.

X:	—for me it was just different. Like I said before, but I am looking at a text book, like there is nothing , it is just pointless. You might read it ten times and you are like 'yeah okay, this is a circuit, this is this, this is that' but 'how does that work in real life? How do I do—' Like we are doing it from scratch, like doing circuits and *you* do it step by step and if you make a mistake you know where you made that mistake. But by a textbook it is like 'oh yeah, if you do this it will go wrong-if you do this it will be right'. And you don't really understand it. I think just *doing* things yourself.

[0:09:48]

X:	It is more practical.

X:	Yeah.

X:	Yeah.

X:	I think even actually doing it with like the actual circuit that we—I don’t know if they actually got to do it, but we actually got to do it—but still like, on the computer it has more options of what you can do, and if you do it wrong you can just delete it and go again rather than you have one light bulb and one battery and that is all you get to work with. It is easier if you have it on the computer and you can put as many as you want in, because you understand it more.

X:	Yeah. It shows that there are loads of different kinds of circuits. Like sometimes in textbooks it only shows you one simple one. And yeah.

CW:	And the problem just on the Christmas tree lights, have you ever thought about that before or was that a new thought for you?

X:	I didn’t know the difference between the series and parallel one—

X:	I didn’t really know how like—I knew like.

X:	[I just thought that everything was one circuit] I am sorry.

CW:	no, no, no

X:	—I just thought that everything was [one circuit]. I never knew there was parallel and series thing. So I just thought [unintelligible].

CW:	You were going to say something were you?

X:	I knew about it before because my Dad told me about it. Before Christmas when he was putting the Christmas decorations up, one bulb was gone and he had to go through every single light to see if it was working. I thought it was funny!

[laughing]

[Thanks and interview ends [00:11:08]]

Appendix H Technology Artefacts

The attached CD (or Memory Stick) at the back of this dissertation contains the PhET Circuit Construction Kit microworld and other supporting simulations used this research.

Links to the PhET website and the associated resources are also provided below.

Circuit Construction Kit

https://phet.colorado.edu/en/simulation/circuit-construction-kit-ac-virtual-lab

Ohm's Law

https://phet.colorado.edu/en/simulation/ohms-law

Resistance in a Wire

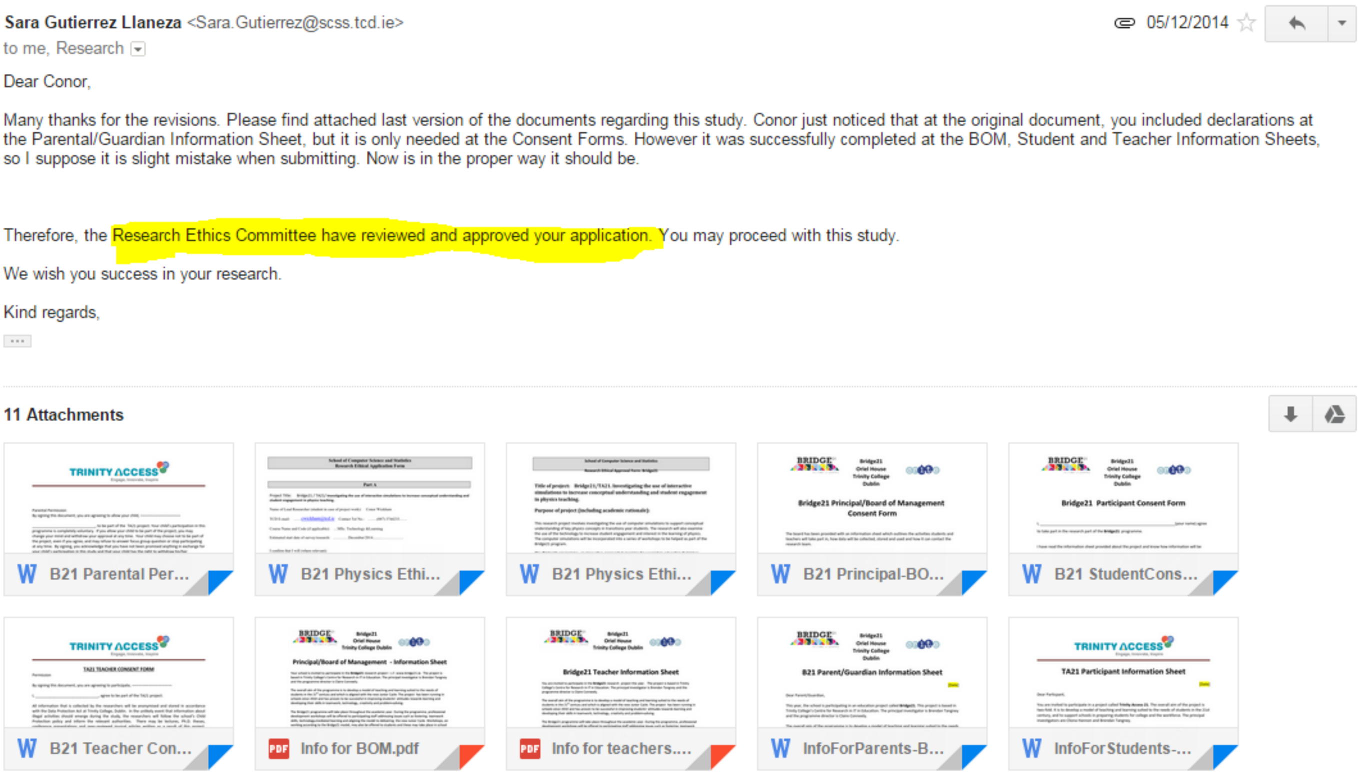
https://phet.colorado.edu/en/simulation/resistance-in-a-wire

Appendix I Ethics Approval

Prior to conducting the research full ethics approval from The University of Dublin's Research Ethics Committee was required. The initial ethics submission was made on November 3rd 2014 and final approval was received December 5th 2014.

The approval email from the Research Ethics Committee is shown below together with the document attachments that were submitted for approval.

Signed Student and Parental approval forms from participants were received prior to the workshop.


Sara Gutierrez Llaneza <Sara.Gutierrez@scss.tcd.ie> 05/12/2014
to me, Research

Dear Conor,

Many thanks for the revisions. Please find attached last version of the documents regarding this study. Conor just noticed that at the original document, you included declarations at the Parental/Guardian Information Sheet, but it is only needed at the Consent Forms. However it was successfully completed at the BOM, Student and Teacher Information Sheets, so I suppose it is slight mistake when submitting. Now is in the proper way it should be.

Therefore, the Research Ethics Committee have reviewed and approved your application. You may proceed with this study.

We wish you success in your research.

Kind regards,

11 Attachments

B21 Parental Per...
B21 Physics Ethi...
B21 Physics Ethi...
B21 Principal-BO...
B21 StudentCons...
B21 Teacher Con...
Info for BOM.pdf
Info for teachers....
InfoForParents-B...
InfoForStudents-...

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