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Engagement and Collaboration in the Effectiveness of Games for Learning Primary School Mathematics

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Dedication

I would like to dedicate my thesis to my grandparents, my father and the rest of my family who were constantly encouraging me. To my sweetheart husband "Wajdi" who deserves my thanks for his patience, understanding and support during this journey. I could not have survived all these years without all of you in my life.

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Abstract

Since the arrival of the personal computer in the early 1980s people have been advocating the use of computer games in aiding teaching and learning. However the increasing prevalence of computers in the early years of the 21st century led to the introduction of the idea of the "digital native" – those who were born since the dawn of the age of the ubiquitous computer. It was then argued widely that this generation would now need to be taught using computer games and that conventional education was not working. This view has been modified since but there still exists arguments for the use of computer games in many areas of education. This thesis looks at the potential benefits of computer games in aiding the teaching of mathematics in primary schools. The particular focus of the research has been whether collaborative computer games if properly designed with the learning outcomes encoded in the game mechanic would be more valuable in promoting engagement with mathematics problem solving than other more conventional methods. A number of hypotheses were developed based on the current theories and designed to be tested for validity.

To carry out this investigation a number of studies have been undertaken. A literature review was focused on the methods

used to teach mathematics in primary schools, the value of collaboration and the use of computer games in education. This was followed up with a study in a primary school to validate the basic findings from the literature review. A user centred design study began with a trial of a commercial game that was meant to promote collaboration in primary school children's game play to ascertain what components best promoted collaboration. Interviews with teachers and pupils were also used to develop the ideas behind a game that was suitably themed for the age group. This was then pilot tested for playability and usability along with a dice game that had been adapted from some commercially available games for use in a later controlled experiment in which the effectiveness of the game designed was tested against the control with groups of children from the UK Key Stage 2 (7 to 11 year olds).

The hypotheses were evaluated against the results of the controlled experiment. The idea that computer games themselves would always work in promoting learning were disproved but the value of games (both computer and non-computer games) as an adjunct to conventional teaching in collaborative settings was shown to be valuable in promoting engagement with mathematics. It was also clear that these games promoted learning among those who were in the group of low achievers in mathematics.

Publications

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Al-Washmi, R., Baines, M., Organ, S., Hopkins, G., & Blanchfield, P. (2014). "Mathematics problem solving through collaboration: Game design and adventure", In 8th European Conference on Games Based Learning (Proc. ECGBL 2014), Berlin, Germany, 9-10 October, 2014, pp 1-9.

Al-Washmi, R., Bana, J., Knight, I., Benson, E., Afolabi, A., Kerr, A., Blanchfield, P., & Hopkins, G. (2014). "Design of a Math Learning Game Using a MinecraftMod", In 8th European Conference on Games Based Learning (Proc. ECGBL 2014), Berlin, Germany, 9-10 October, 2014, pp 10-17.

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1 Introduction

The term "digital native" (Prensky, 2001a) has recently gained a lot of credence. The idea behind this is that in the 21st century children are exposed to computers in every aspect of their lives from their earliest years. There is research into how this may be affecting their actual development but those who were responsible for coining the term were more interested in how this was going to impact the ways they would develop and would prefer to learn (Prensky 2001b; Gee 2003; Gee 2004; Gee 2005; Shaffer 2005; Shaffer 2006). Prensky has to a certain extent modified his views on this and now uses the term "Digital Wisdom" (Prensky 2009) but the term is still common in research about the subject of computer games based education. This has been seen against a background in the USA and the UK of a lack of progress in learning among young people relative perhaps to the rest of the world (Dowker, 2009; DfES, 2012). It has been argued that digital natives will find conventional learning approaches unappealing and disengaging. This has led to much research in the use of computer games in education. Two groups could potentially be involved in taking up these developments. The first is the educators who are eager to encourage engagement in their classes. The second is the games producers who see the potential of games in engrossing players and therefore feel games could and should be used in teaching. However, there are few educators who actually understand how games work and few game producers who know how the pedagogic imperatives can be included in their game design. As a result much of the work done in the area of computer games based learning has not been very successful. Prensky (2011) has specifically criticised the work of others. It is his contention that the major problem has been the lack of really well designed games that have been produced and that much of the academic work to test them has been limited. This latter point is probably because of the difficulty of undertaking the sort of experiments that will be conclusive. Access to schools is not easy to achieve and collaboration with educators is vital if games are to be properly tested.

The motivation in looking at computer games for educational purposes is encouraged by the current difficulties in promoting learning in schools in the UK and the USA. While there is no certainty that computer games will have a significant effect in this there are apparent needs to encourage learning and especially in the core subjects. Learning of mathematics can be found to be more difficult than other subjects. It is often a challenge to engage those students who are weak in the subject. Different approaches are taken and the use of both games and collaborative exercises are found to be effective for some but less effective for others. Of the mathematics learning that young children are introduced to, problem solving can often be the most challenging. Some studies indicate that collaborative exercises can be helpful in learning mathematical problem solving. However, some research seems to suggest that younger children do not respond well to these exercises. Reasons given for this are the unwillingness of the more able to share their knowledge as it is felt that they will get less reward for their knowledge if they do and the parallel lack of desire of the less able to expose their lack of knowledge in open classroom activities. On the other hand casual observation of children playing games would suggest they are very happy to play collaboratively in these circumstances. Work with secondary school students has certainly suggested that this carries over to educational games (Che Pee, 2011) for this older age group.

These possibilities and challenges therefore introduce a number of possible research questions that would be important to test. They will investigate the possible value of collaborative educational computer games in promoting learning and the use of computer games themselves in promoting that cooperation. Differences in response for different children are also suggested. The question of whether the less able children would be less motivated to cooperate would for example be significant. Four research questions were thus developed and one of these was also framed as an alternative hypothesis. These are given below.

1.1 Research Questions

Research Question One (RQ1)

Can computer games aimed at UK Key Stage 2 children (ages 7 to 11), and designed by integrating a collaborative approach to the teaching of mathematics enhance pupils' engagement with learning mathematics and further motivate them to learn?

This research question is indicated by the general promotion of games based learning and the success of using such methods with older children.

Research Question Two (RQ2)

Do computer based games engage and motivate digital native students better than conventional dice based games?

If the ideas behind the theory of children in the 21st century being "digital natives" are true this research question should be confirmed.

Research Question Three (RQ3)

Are children in the Key Stage 2 age range capable of collaborating? If so how can this be encouraged in game play activity?

This research question will test the theory of some that this age range is capable of collaborating and of others that they are not.

Research Question Four (RQ4)

Will children with low maths ability find it difficult to engage with the gameplay or collaboration and will they therefore not engage with or learn the mathematics?

This research question will test whether ability to collaborate is affected by maths ability and, if not, whether this type of game has the potential to improve problem solving skills in children with low maths ability.

Research Question Five (RQ5)

Will the use of a mixture of game based learning with conventional learning encourage children to learn maths and maths problem solving? And how will this be indicated by improved attitudes to the subject and study?

If children enjoy their study more they should be more willing to engage with it and motivated to take part. It would be expected in the long term that this would produce better learning.

1.2 Objectives

The research questions stated above therefore introduce a number of objectives. The first consideration is how correct is the theory that computer games will be needed to promote learning for "digital natives?" A second consideration of importance is, "To what extent will children in the Key Stage 2 age group be prepared to cooperate and what evidence is there for this?" A further consideration is that if it is necessary for games to be good in order to work as educational games what aspects of games would be seen as "good" by this age group and additionally how can games encourage collaboration through their game play? The following objectives can thus be framed:

1. To undertake a background literature study in the approaches to teaching mathematics and the use of computer games in education.
2. To undertake an observation study in the classroom. This will serve three functions:

    1. To evaluate whether the literature is seen to be correct in terms of observed practice in a modern classroom.
    2. To establish good relationships with a school to facilitate the later testing of the games.
    3. To identify initial requirements for a prototype collaborative game environment.

3. To examine practically whether children in the age range cooperate with each other when playing computer games and whether a commercial game specifically designed to encourage collaboration actually does so for this age group. It should then be possible to identify aspects of the game design that would encourage users of this age range to cooperate in play.
4. To design the game and pilot test it to ensure that it works as a game as well as engaging players with the learning material.
5. To design or obtain a suitable non computer based game to use with a control group.
6. To undertake a control based trial in a classroom situation for a period of five weeks.
7. To appropriately analyse the results of the study in order to answer the research questions and hypothesis posed in this chapter.

1.3 Thesis structure

This thesis is divided into eight chapters. The current chapter has introduced the motivation for the study and five research questions to be answered. It is believed that these research questions formulate an argument that will challenge a number of current beliefs about the use of games in classroom situations.

Chapter two presents a review of the literature which focuses specifically on learning in maths, computer games in education and collaboration. This aims to give a background understanding of the learning process and the use of computer games to promote learning and collaboration. The chapter highlights different issues such as teaching mathematics, maths learning difficulties, problem solving, collaborative learning, and the importance of games within learning environments and their impact on pupils' learning. A number of ideas have been identified that have been further investigated in later chapters.

Chapter three outlines the methodology used for data collection in this PhD. The methodology section contains an overview of the research approach, a research outline for the methods adopted in the research and introduces the different techniques that have been followed for collecting the data and analysis. The chapter concludes with a section on the challenges encountered through the investigation of this PhD.

Chapters four and five give the background to the design outlining experimental studies as part of the design cycle in order to complete the design aspects of the objectives. Chapter four presents results from observations of the original classroom environment and shows that games do play an important role in the classroom and that children can collaborate. Chapter five presents results from observations of children playing a popular commercial entertainment game (Harry Potter Lego) designed to encourage collaboration. Results indicate that in order to make a game engaging and to encourage collaboration the game needs to be designed to incorporate elements of curiosity, fantasy, have clear goals and storyline as well as having well-structured rules.

Chapter six looks at the actual game design process and usability testing of the game. Usability testing showed that children did collaborate with the game that was built but that there needed to be a way for teachers to change the difficulty level for different pupils.

Chapter seven presents the final study of this PhD and looks at the results from the five week controlled experiment. The design of a collaborative non-computer game (control game) was presented in this chapter. The chapter then moves on to report on a pilot study undertaken to validate the games before reporting on the main study. Results showed that some pupils' maths ability improved through use of the computer game and these were particularly pupils who initially had low maths ability. However the dice (control) game also showed improved maths ability demonstrating that a game does not have to be computer-based. Results indicated that ultimately encouraging collaboration and engagement with the game mechanic can improve maths ability if the game and experiment are designed well.

Chapter eight draws the conclusion. The results of all the studies are reviewed and discussed in detail in this chapter in relation to the research questions. The contributions of this research are presented with specific findings highlighted. The thesis limitations are outlined with suggestions for further work.

1.4 Contributions and Key Findings

Throughout the thesis a number of key findings and contributions to knowledge have been made which are highlighted here.

Chapter four investigated ways in which teachers try to engage pupils in the mathematics classroom and why pupils can lack enthusiasm. The chapter presents a key finding that collaboration is helpful for those who find mathematics problem solving difficult even in this age range and that pupils are capable of collaborating (RQ3).

Chapter five presents a second study involving observations of children playing a collaborative computer game and questionnaires. The key findings were that children did indeed collaborate during the game-play showing that computer games can be a useful tool in facilitating the process of collaboration. It was also found that collaboration can play a significant role in promoting engagement with game play.

Chapter six presents the design of the game used to evaluate the role of collaboration in the learning of mathematics problem solving. Key findings are that children can collaborate and share experiences both within and between pairs of players during game play (RQ3) but that there needs to be a way of adjusting difficulty to support player diversity and maintain flow.

Chapter seven reports on the main study which aimed to evaluate the role of both collaboration and engagement with the game mechanic in promoting motivation and supporting the learning of mathematics problem solving. Key findings were that there was no significant improvement in learning demonstrated for the whole group (RQ2) but that there was a significant improvement in collaboration, engagement and motivation for pupils who were weaker in mathematics and consequently an improvement in maths ability in these pupils (RQ4). Two significant contributions of the thesis are presented: computer games in their own right do not necessarily enhance learning even if they are designed well and encode the learning outcomes in the game mechanic; and learning environments are most effective when they use a combination of teaching methods and strategies but collaboration is key in their success (RQ5).

2 Literature Review

2.1 Introduction

Learning is a persisting change in behaviours and performances which results from the interaction and experience with the environment surrounding the learners (Driscoll, 2000). It is a process whereby knowledge and experience is gained and which can be applied in different life situations (Steinkuehler, 2010).

Mathematics is one of the most important subjects taught in the early stages of education. It encourages children to be intellectually active which promotes the building and development of learner’s knowledge and skills. De Corte et al. (2000) defined learning mathematics as a process of active construction where learners themselves need to take control of their learning and activities of problem solving. Mathematics skills and knowledge play a significant role in several academic areas such as developing a foundation in science and technology as well as in longer term areas of career development. However, 10% of UK children aged 7-11 years old have difficulties in reaching the required level of mathematical skills in formal education (DfES, 2012).

The importance of problem solving skills within the curriculum and their role in learning mathematics has long been recognised (Suydam, 1980; Branca, 1980). The National Council of Teachers of Mathematics (NCTM) in the UK (NCTM, 1980) confirmed that teaching mathematics should be based on problem solving due to the importance of such skills and functions in everyday life. Stanic and Kilpatrick (1989) reinforced that problem solving is an important component of mathematics education because of its practical role to the individual and society. Learning mathematics through problem solving can create an environment which simulates real life and it can help students adapt to the changes and unexpected problems in their careers and other aspects of their lives. Thus, the NCTM endorsed this recommendation (NCTM, 1989) with the statement that problem solving should underlie all aspects of mathematics teaching in order to give students experience of the power of mathematics in the world around them. It has already seen that many children struggle with mathematics and problem solving and this therefore means that many children struggle with a subject which is core to building various life skills and to helping children progress into their adult life with the ability to deal with daily challenges. This therefore leads to the question of how to help children build on their mathematical and problem solving skills. There has been a significant volume of research conducted into the support for learning mathematics provided by games (Malone, 1981; Moreno, 2002) although researchers have not always agreed on the effectiveness of games for such purposes. However, there is also considerable opinion that the style and design of games is an important influence on the effectiveness of such games. In particular the effectiveness of a game in achieving learning outcomes depends on how effectively those learning outcomes are integrated into the game mechanic in an interesting manner (Habgood, 2007; Habgood and Ainsworth, 2011).

There is empirical evidence supporting the positive effects of using computer games in classrooms to help students learn basic arithmetic and problem-solving skills (Inkpen, 1994). However, O'Neil et al. (2005) proposed that computer games are not effective in isolation but should be used in conjunction with other instructional supports. Therefore, successful use of computer games in the classroom depends on the quality of the teaching, including the teacher's skill in diagnosing pupils' abilities, identifying learning objectives and developing games in appropriate ways to meet those objectives (Sanford et al., 2006).

Additionally integrating technology into the learning environment can be effective by enhancing collaboration, motivation and engagement (Ke, 2008a; Cortez et al., 2009; Plass et al., 2010a). Computer games provide an interactive environment within which players can engage and explore and test their understanding but they also offer the opportunity for collaboration with other players within the game-play. Children acquire and build their knowledge depending on the reality of the world, and people around them such as teachers and parents (Leonard, 2002). External stimuli play a key role in extrinsic motivation to engage with a particular activity (Ryan and Deci, 2000). According to Niemi (2007) there is a relationship between engagement in school and interest in learning whereby the loss of a sense of engagement within school will lead to a loss of interest in learning. The educational system has emphasised the importance of pupil engagement in school and there is significant evidence of a relationship between engagement and achievement in students' learning (Dalun et al., 2011; Dotterer and Lowe, 2011).

Learning and teaching therefore relies on children's social experience and those people around them in the learning environment (Bigge and Shermis, 2004) and this plays an important part in their cognitive development. Within learning environments collaboration can play an important role in stimulating learning as pupils collaborate and interact with each other (Powell and Kalina, 2009) as well as the teacher.

2.1.1 Summary

This section has introduced the importance of mathematics and problem solving in establishing skills for adult life. Computer games-based learning has been shown by some to be potentially useful in supporting the learning of maths problem solving as has the incorporation of collaboration in learning environments.

The research in this PhD examines the role of collaborative computer games in supporting mathematics problem solving in the classroom. This chapter therefore presents a review of the literature on teaching mathematics, games-based learning and collaboration in the classroom. The next section begins with an examination on how mathematics and problem solving in particular are taught in the classroom and methods used to aid this. Following this the chapter moves on to discuss computer games-based learning. The chapter concludes with a consideration of collaborative learning and mechanisms used to promote collaboration. Within this section collaboration is discussed in terms of its importance in the learning process and the role that computer games might play to enhance these.

2.2 Background

2.2.1 Learning Mathematics

Mathematics is an important subject involving several principles and skills that should be practiced in primary education in order to be learned. According to Piaget (1983) the concrete operational stage (between 7 and 12 years old) can be defined as the third stage of Cognitive Development Theory in which a child is capable of performing a variety of mental operations through development of logical thought using concrete concepts, however they still struggle with abstract ideas. In other words, children will have the ability to understand basic arithmetical processes like subtraction, multiplication, division, and addition. However, the children's abilities to systematically solve problems with multiple variables will be difficult at this age (Bryant et al., 2000; Dowker, 2009).

In primary school, the mathematics instruction is focused on many areas such as arithmetic fact fluency, operations, and problem solving (Fuchs et al., 2006; Gersten et al., 2009).

Tambychik et al. (2010) have proposed five broad skill categories, listed in Table 2.1.

Skill Category	Description
Number facts	Proficiency of number facts, tables and mathematics principals
Arithmetic	Accuracy and logarithms in computational and mathematical working-procedures
Information	Expertise to connect information to a concept, mathematical operations, and experience as well the expertise to transfer information and transform problems into mathematical sentences
Language	Proficiency of terms and relevance of mathematical information
Visual-spatial	Skills to visualize mathematical concepts, manipulate geometrical shapes and space meaningfully

Table 2-1: Mathematical Skill Sets (Tambychik et al., 2010)

These skills have been translated into a number of learning outcomes in the UK National Curriculum for mathematics (DfE, 2013) and these are shown as follows:

1. Pupils are confident and fluent in the fundamentals of mathematics by frequent practicing, so they can solve

complex problem efficiently over time due to the enhancement of their ability to recall and apply knowledge rapidly and accurately.

2. Pupils can choose appropriate methods to apply their mathematics knowledge and skills to solve any mathematical problems which can take sophisticated forms, including routine and non-routine problems.
3. Pupils can explain their solution using the language of mathematics in order to prove that they fully understand mathematics concepts. Thus, it will be easy for them to give mathematical reasons, justification and proof by following a line of enquiry.

Many researchers have conducted significant studies in understanding the progress of children's mathematical knowledge development in counting and calculations (Compton et al., 2012, Baumert et al., 2012). Children are able at age 8 to recognize arithmetic symbols and do basic addition and subtraction, children learn to solve easy problems first, and then continue with more difficult problems when they get older using multiplication and division, along with triple-digit arithmetic between ages 9 and 12. Compton et al. confirmed that children at year 3 start to obtain foundation knowledge of numeracy and arithmetic, however, proficiency in mathematics will be attained fully at the end of primary school (Baumert et al., 2012).

The learning outcomes shown above highlight the importance of teaching mathematics through problem solving which can be a major challenge for students because it depends on the possession of several mathematical skills. It is not uncommon for children to experience difficulties in developing these skills and meeting the learning outcomes. The next section further looks at the importance of problem solving and the skills and knowledge required for this.

2.2.2 Problem Solving

Problem solving is at the heart of mathematics (Cockroft, 1982). According to Mayer (1982) solving problems involves several processes using different forms of knowledge that lead to knowing the problem goals. This knowledge can be categorised into different types as follows:

1. Strategic knowledge – about how to approach problems;
2. Linguistic and factual knowledge – about how to encode statements.
3. Schema knowledge – about relations among problem types.
4. Algorithmic knowledge – about how to present distinct procedures, and use appropriate operations.

Problem solving has been defined as a process of learning which draws upon intelligence, learning, thinking and cognition (Mayer, 1992). In addition, problem solving entails many mathematical concepts like arithmetic, algebra, and geometry, and it involves a variety of complex skills. Problem solving is significant in developing student's skills in many learning fields, for example the sciences (Lester et al., 1994).

Anderson (1993) confirmed that problem-solving skills have been observed in upper primary grade children aged 8-12 years. It gives students the opportunity to develop their confidence and ability to think mathematically (Schifter and Fosnot, 1993) and benefits' learning in that it makes use of previous experiences and information already held by learners (Lester et al., 1994). Learners can acquire knowledge and learn within the context of the problems and thus improve their problem solving skills.

The NCTM in the UK also has emphasised the importance of problem solving as an integral part of the mathematics curriculum (NCTM, 2003). Researchers agree to the importance of including problem solving activities in today's classrooms (Lovitt, 2000; Rogers, 2004).

A number of other researchers have also illustrated that primary school students are capable of using different problem solving strategies like drawing, making tables and using logical reasoning to solve problems (Follmer, 2000; Cai, 2003). A study by Outhred and Sardelich (2005) confirmed that children can engage with different activities like drawing and writing solutions to problems as well as writing their own problems during mathematics classes. Indeed, recently the curriculum has changed to incorporate problem solving in order to enhance many important mathematical learning skills such as thinking, communicating and instilling deep understanding (Muir et al. 2008).

To summarise, problem solving is a process of thinking where students use their mathematical knowledge and attempt to obtain new information in order to solve problems. Although the development of problem solving skills can provide benefits as discussed earlier, difficulties in learning mathematics still can be faced by children. The National Council of Teachers of Mathematics (NCTM 2008) promotes the importance of engagement into different activities to facilitate learning and limit learning difficulties. The next section will discuss engagement with learning mathematics and its aspects and how they can contribute to the learning process.

2.2.3 Engagement with Learning Mathematics

There have been extensive studies of children's engagement in elementary and middle schools (Fredricks et al., 2004; Roorda et al., 2011). Engagement in school can be divided into three dimensions: behavioural engagement, emotional engagement and cognitive engagement (Appleton et al., 2008; Annetta et al., 2009). Firstly, behavioural engagement is expressed during study and practice in school through positive behaviours such as perseverance and adherence (Fredricks et al., 2004). Secondly, emotional engagement is where students express willingness to work via different feelings towards teachers, peers and activities. Finally, cognitive engagement is a reflection of students' thinking through their behaviours when they desire to do certain actions and activities.

In addition to the significance that engagement plays in students' learning (Oncu, 2007; Charles et al, 2009), especially in mathematics (Bodovski and Farkas, 2007), engagement is considered a necessary condition of learning (Appleton et al., 2008). Indeed, engagement has been strongly associated with academic achievement of learners (Dotterer and Lowe, 2011).

In summary, engagement with school can be expressed through different students' positive or negative attitudes towards school (Mandernach, 2009). School engagement is vitally important and may have an impact on the achievement of students' learning both directly and indirectly within the classroom context (Dotterer and Lowe, 2011).

The next section therefore examines the methods used in the classroom for teaching mathematics and how they can contribute to engagement by children in the learning process. The questions here are what methods and/or tools have already been tried in teaching mathematics and problem solving, how effective have they been and to what extent have they been shown to engage pupils in the learning process?

2.2.4 Methods Used for Teaching Mathematics

In the past, teaching mathematics was often based on traditional teacher-centred methods. Palincsar (1998) indicated that the traditional method of teaching mathematics has always been to impart knowledge through telling and showing children how to obtain the correct answers, and then to emphasise the skills that have been used, getting them to practise the skills as much as possible. It is important to be aware that giving children rules and techniques in this way may lead them to apply mathematics without an understanding of the principles that mathematics is based on. This argument was put forward by Piaget in 1953:

"It is a great mistake to suppose that a child acquires the notion of number and other mathematical concepts just from teaching." (Piaget, 1953, p. 74)

Peterson and Walberg (1979) emphasised that direct instruction can be effective in teaching factual mathematics content. Several studies, into different age groups, have also demonstrated that direct instruction can be successful in teaching problem-solving (Fuson, 2003; Xin et al., 2005). However, whilst direct instruction is viewed by some as an effective method for teaching problem solving it is viewed by others as having flaws in its ability to teach higher order mathematical skills and principles. Harskamp and Suhre (2007) believed that this method can cause failure to apply problem solving strategies and difficulties in understanding solutions.

There is limited evidence to show whether this method can transfer higher order cognitive skills to children, such as analysis of the activity, or whether it equips children to be able to reason about problem solving especially when the problem is presented in novel contexts. Therefore, many educators have recommended the enrichment of maths lessons with lots of concrete resources in order to facilitate teaching maths at primary schools. The thought is that utilising tangible objects can encourage children to solve arithmetic problems; contribute to making children more capable of solving abstract problems, and can increase children's confidence to enable them to transfer their learning to others through discussion and giving reasons for their solutions (Haseler, 2008; Thomas and Allingham, 2008). However, other researchers believe that concrete procedures are not enough for children to understand the concepts of maths problems because it is sometimes hard for children to make the connection between the tangible objects and/or concrete situations with numbers and particular types of problem (Dowker, 2005; Hannell, 2005).

In addition, many awareness-raising sessions for teachers have stressed the importance of integrating different methods such as collaboration (Ding et al., 2011) and games (Prensky, 2003; Ke, 2008a, Connolly et al., 2012) which can contribute to the development of pupils' mathematical thinking and problem solving abilities and make the mathematics learning process more effective. Later on in this chapter both game based learning and collaboration will be revisited in more detail in section 2.3 and section 2.4.

To summarise, different studies of teaching mathematics have shown different evidence but ultimately the effect of these methods will depend on the types and number of strategies used and the individuals involved, both teacher and pupils, especially when carried out by an effective teacher (Ryzin et al., 2007; Ryzin, 2011). Mathematics teachers strive to teach skills to children in a number of ways to achieve the learning outcomes of the National Curriculum for mathematics in the UK, however, evidence suggests that some children experience considerable difficulties in mathematics especially problem solving where the target can be obvious but not easy to reach (Altun, 2005). The next section moves on to examine the research into mathematics and problem solving difficulties experienced by children.

2.2.5 Difficulties Experienced in Mathematics and Problem Solving

Problem solving difficulties can occur at any phase of the problem-solving process (Newman, 1983), i.e. at the reading, comprehension, strategy know-how and any of the transformation process or solution stages. Kroll and Miller (1993) illustrated three major factors in solving mathematics problems: knowledge, control (metacognition) and beliefs. They suggested that a defect in any of the three can cause difficulties in solving problems.

Kaur (1995) confirmed, in a study, that pupils faced the following difficulties whilst solving mathematical problems:

1. Lack of comprehension of the problem posed.

2. Inability to translate the problem into a mathematical form.

3. Lack of the different strategies of mathematical knowledge.

Problem solving is a complex process of learning that can involve many sub-problems (NCTM, 2000). Harskamp and Suhre (2007) attributed students' difficulties in solving problems to copying standard solution methods provided by the textbook or teachers without understanding or thinking about the whole process. Students' failures at solving problems are not often the result of a lack of mathematical knowledge but an indication of the ineffective use of their knowledge (Harskamp and Suhre, 2007), including their self-knowledge involving experience and previous knowledge. The importance of the involvement of problem solving skills in the process of learning, through practice from an early age is clear from this study.

There is consensus among researchers that mathematical difficulties faced by children often correlate with problems in areas like memory, language difficulties and/or spatial difficulties (Gifford, 2005; Hannell, 2005). Dowker (2009) classified these three mathematics difficulties as follows:

1. Difficulties with memory that affect arithmetic can be of two main types: problems in storing and/or retrieving arithmetic facts in long-term memory, and problems with working memory which involves organising and keeping track of items and their order in memory while using these to solve problems. Problems with working memory can have a particular impact on mental arithmetic, where children may have trouble in keeping track of their steps in solving an arithmetic problem, and may forget the first step in solving an arithmetic problem by the time they get to later steps. This difficulty may be one reason for the fact that multi-step arithmetic is one of the aspects that children often find difficult. Difficulties in arithmetic are sometimes associated with rather specific memory problems for numbers – in which case it can be hard to tell which is the cause and which is the effect – but such difficulties are sometimes associated with broader problems in verbal memory, spatial memory or both.

2. Language difficulties can increase the problem. This is because it can affect children’s abilities to understand and make use of instruction and it can confuse them so they will not be able to encode and represent mathematical information. Thus, it affects their ability to choose useful strategies in order to solve the problem.

3. Visual-spatial difficulties will have particularly direct impact on such topics as geometry and measurement, but may also affect arithmetic. This is because it may affect children's abilities to set out numbers and arithmetic problems in written form, and their ability to use and understand some of the concrete materials used in teaching arithmetic.

Of these three mathematics difficulties, the first is particularly important in this thesis. According to several research studies (e.g. Cumming and Elkins, 1999; Gifford, 2005) the most consistent difficulty that children have is in retrieving arithmetic facts resulting in an excessive reliance on counting strategies. Mathematical words can cause difficulties (Russell and Ginsburg, 1984) and multi-step arithmetic activities with a large number of steps can lead children to difficulties (Bryant et al., 2000; Dowker, 2009).

Additionally many researchers (e.g. Hitch and McAuley, 1991 and Swanson, 1993) confirmed that children with learning difficulties specifically in arithmetic have poor achievement in manipulating and transforming material to solve mathematics problems that require remembering information. Therefore, these children usually have slow and inaccurate computation performance.

The importance of working memory as well as long term memory can be seen in the activities required to problem solve. Therefore, this thesis is particularly focussed on how collaborative computer games can facilitate these difficulties in storing/retrieving facts from long term memory and help keep track of/organise information in working memory and their role in problem solving.

2.2.6 Summary

Teaching mathematics through problem solving is important but challenging for pupils because a range of skills are needed and difficulties can be experienced with memory, language and/or spatial difficulties. In order to address these challenges, finding ways of promoting engagement with problem solving is key and a range of methods has been used in the classroom to do this. Some methods have been used with more success than others and evidence suggests that the use of games and collaboration within the classroom can help.

The next section looks at the use of mathematical software and, more specifically, the use of gaming in the classroom and ultimately leads on to the topic of this PhD which is to investigate the effectiveness of computer games in engaging pupils in learning environments that aim to teach mathematics problem solving.

2.3 Game Based Learning (Related Work)

2.3.1 Serious Games

Serious games are defined as games that have learning as their purpose (Stone, 2005; Michael and Chen, 2006). Serious games in the field of education are widespread and offer an inspiring area of research into instructional tools which can be used to enhance learning (Ke and Grabowski, 2007; Coller and Scott, 2009). They give enormous opportunities for learners to link daily life experiences and skills using different learning styles (Proserpio and Gioia, 2007; Vahey et al., 2007).

Prensky (2003) indicated that the importance of serious games lies in the understanding of the games' ability to change part of the way learning happens (Gee, 2004). Educators believe that children learn best during play and that games give them that opportunity (Gee, 2003; Morgan and Kennewell, 2005). Learning depends not just on playing but on several fundamental factors (Gros, 2007) and different conditions are required for learning to take place. For example, a game should include several learning methods such as observation, problem solving, sequence learning, deductive reasoning and memorizing and the game content should encapsulate the context of core information and its meaning. In doing this humans can acquire several skills through playing without realising and playing can be considered as something that offers a natural and universal learning tool for children and adults (Prensky, 2005).

2.3.2 Games as Learning Tools in the Classroom

A study of Ota and Dupaul (2002) confirmed that games can be effective tools for learning, understanding the instruction and the concepts of mathematics, arithmetic and problem solving. Serious games aimed at primary school age children are considered especially useful tools in facilitating teaching and learning as they enable information to be conveyed in a fun manner. They also enable knowledge to be enhanced particularly in scientific fields which can be the hardest area for children (Williams et al., 2005; Barab et al., 2009). Papastergiou (2009) indicated that learning through gaming improves both knowledge of the embedded subject matter and student enjoyment, engagement and interest in the learning process. Furthermore, educational games can enhance learners' engagement towards learning which can increase achievement (Charles et al., 2009). Therefore, using technological devices such as computers in the classroom has proven to be effective in achieving motivation (Ke, 2008), collaboration (Cortez et al., 2009) and learning results (Carbonaro et al., 2008; Plass et al., 2010) but learning is also dependant on integration of the learning outcomes with the game mechanic (Habgood, 2007; Habgood and Ainsworth, 2011).

Computer games can therefore be beneficial learning tools which suit young children and support learning in an enjoyable way (Couse and Chen, 2010). This is particularly so because the recent generation has been born into and has grown up in a technology-dominated world where playing with computer devices is common (Bekebrede et al., 2011). There is considerable opinion that the style and design of games is important in the effectiveness of such games in promoting learning. The next section discusses game characteristics in more detail.

2.3.3 Game Characteristics

Several researchers have indicated that game characteristics are an important part of a game's design because they contribute to the formalization of play. They also help to transfer play from a free form activity to a structured activity but without ignoring the sense of fun (Crawford, 2003; Koster, 2005).

Game characteristics have an important role as attractive and stimulating elements for children in order to enhance and facilitate learning (Aldrich, 2004, 2005). However, there are conflicting views of the researchers regarding the most important characteristics that must be in the game.

Malone (1981) argued that there are four characteristics of games that make them engaging educational tools: challenge; fantasy; complexity and control, while Crookall et al. (1987) said that game features can be centred on rules, strategy, goals, competition, cooperation, and chance. Moreover, Thornton and Cleveland (1990) considered interaction to be the essential aspect within the game. In addition, De Felix and Johnston (1993) added several things like dynamic visuals, rules, and a goal besides interaction, and they considered these as the structural components of the game. Prensky, (2001) has emphasised the importance of six game elements within the development of computer games which are story, rules, goals and objectives, outcomes and feedback, conflict/challenge and interaction. In other words, storyline can be an effective incentive in order to investigate play processing and how the processing of the story with curiosity, suspense and surprise influences the players' interactions to solve educational problems. Rules may be identified through game structures like scoring and timers to allow learners to achieve desired goals. Providing feedback through playing can be useful to guide players onto the right path and contributes to facilitate reaching the goal.

Rollings and Adams (2003) confirmed that several games have used similar characteristics as core to the game design but they have been used in varying ways to create a unique game experience for the players (Rouse, 2005). For example, games that are based on puzzles can involve several kinds of puzzles regarding difficulties and/or concepts. This would enhance the player's motivation each time to solve different kinds of puzzles in order to reach the goals.

Beetham (2008) added that using specific tools and resources towards specific outcomes leads to the interaction between students and create attractive learning environment. Other researchers have proposed different classifications of game characteristics such as challenging activities (Rouse, 2005), fantasy elements (Iuppa and Borst, 2007), interesting choices (Juul 2005), rules (Charsky 2010, King et al., 2011), and competition (Staiano et al., 2012).

Challenge within the games are considered to be the essence of gaming by providing meaningful feedback for addressing such problems when playing games (Barzilai et al., 2014; Swanson et al., 2011). Furthermore, it has been suggested that challenge in serious games can help learners with complex tasks which require the learners to have an important role and control in order to promote careful thinking.

In summary, a number of different characteristics have been proposed as being important elements of game design, however researchers often do not agree on which are the most important. Fantasy, challenge, complexity and control are cited as being significant, along with the provision of clear goals and rules but there are lots of different opinions as to what an effective learning game needs to engage learners and this is something which needs further investigation for the purposes of this PhD. The next section discusses the literature related to the use of computer games to engage children with the learning context.

2.3.4 Engagement with game based learning

Educational games have been used widely in supporting learning mathematics over the years and results have shown games can positively impact engagement and achievement (Ke, 2008b; Kebritchi et al., 2010). However, other researchers argue that there is still a need for more support of mathematics engagement and achievement in the classroom (Ke, 2008b; 2008c).

Educational games can create great game experiences by involving lots of features that keep players engaging sustainably with the game activities and don’t just motivate them to begin playing, but to continue to play (Brown and

Cairns 2004). According to Kiili (2005) games should involve different levels of challenge in order to cover different players' skills and maximize engagement. The desire of players to continue playing can be important for players' engagement with the computer game activities (Brown and Vaughan, 2009). Furthermore, educational games that have been well designed will contribute to attracting players (Jennett et al. 2008) by capturing their attention during the activities (Rigby and Ryan 2011).

The experience of playing a game can therefore engage players through different aspects such as flow (Csikszentmihalyi 1991; Chen 2007), storyline (Klaila, 2001), immersion (Brown and Cairns 2004; Jennett et al. 2008), pleasure (Costello and Edmonds 2009), motivation (Rigby and Ryan 2011), enjoyment (Klimmt 2003; Ijsselsteijn et al. 2008a) and fun (Koster 2004) and each of these can enhance engagement and deliver a good learning experience.

There are lots of components which can promote flow. These are: clear goals; direct and immediate feedback; balance between ability level and challenge and sense of control involving educational games. Each of these can promote engagement towards student achievement (Shute et al., 2009). The development of engagement with learning has been exhibited as passion to participate in learning activities continuously and consistently (Charles et al., 2009).

Game difficulty plays an important role in the level of students' engagement with a game. If the task challenge is less than the players' ability level, it can cause a decrease in their engagement whereas if the task challenge-level has been designed according to the player's ability, then their engagement can be increased (Hoffman and Nadelson, 2010). Therefore, educational games can be more effective by supporting both engagement and motivation at a constant level during play through the use of different challenges within the learning tasks without any help from the teacher (Gee, 2003, 2008; Rupp et al., 2010). Overall engagement with game play is a significant aspect that links several factors including academic achievement, motivation, desire to continue with a task, and balancing between the challenge level and the player's ability. All of these can determine the strength of engagement (Hoffman and Nadelson, 2010). There has been a huge amount of research on the importance of integrating computer games into learning contexts due to their benefits of promoting learning and engagement and thus achievement (Kapp, 2012; Cheong et al., 2013). The impact of such serious games on learning is an important consideration to be discussed in the next section.

2.3.5 The Impact of Serious Games on Mathematics Learning

Computer games have been used as useful tools to effectively facilitate mathematics learning and can contribute to increasing students' motivation (Betz, 1995; Moreno, 2002). Researchers believe that video games can help to improve the educational achievements of students but they are not considered an essential to teaching (Virvou et al., 2005). Kirriemuir and McFarlane (2004) highlighted several reasons that explain the failure of games in the educational field. Firstly, many educational video games are not engaging for children because they do not incorporate any fun into learning. Secondly, the games may be designed poorly and involve tasks which are not useful for increasing the students' progress, and so they are centred on simple "drill and practice" models (Squire, 2003).

According to some researchers, however, game based learning has presented academic subjects in a more learner-centred, more accessible manner which is more enjoyable, more interesting, and, thus, more effective (Malone, 1980; Prensky, 2003). This is, they say, without ignoring educational objectives which should be included within the game in an interesting manner. Therefore there is a thread of argument which proposes that games offer more interest and hence enhance effectiveness. There is a body of research that states some video games centre on "edutainment", meaning that they do not present any challenge for students to help them develop hypotheses or problem solving strategies (Sancho et al., 2009). Because of this, a combination of educational and game features is considered as an important requirement of game design. However, lots of researchers believe that this kind of design is still a pending task (Moreno-Ger et al., 2008, Villalta et al., 2011).

2.3.6 Summary

Educators believe that play is the best way of promoting learning and games give the opportunity for this. Researchers have proposed various elements that should be incorporated in learning games to make them engaging, such as fantasy, challenge, complexity and control, whilst including clear goals and rules. Incorporating these elements will help engagement with the game and flow through the game to be maintained. However, learning outcomes also need to be encoded in the game mechanic for the game to promote learning.

This PhD focuses on the role that collaborative computer games could play in this and how those environments might be more effective in facilitating mathematics problem solving difficulties. The next section looks at collaborative learning in primary schools, and whether children can collaborate effectively. The role of collaborative mathematics computer games is also discussed in terms of making learning more effective.

2.4 Collaboration

2.4.1 Collaborative Learning

Since the nineteenth century many researchers and studies have promoted the benefits of collaboration in the learning process (Johnson and Johnson, 1989). Collaboration enables creative thinking and sharing of ideas which means that problem solving collaboratively is easier than working individually. Ultimately collaborative learning is multi-facetted, where interaction is key in supporting reflection and experimentation.

Learning within a collaborative learning environment has been described from different perspectives. Dewey (1943) indicated that learning within a school environment creates a series of social, emotional, and intellectual events. Lewin (1947) reinforced this in considering the interaction of people with the environment around them as an important part of understanding behaviours and learning about others.

Learners who are sharing the same collaborative learning environment tend to have the same goals as their peers Lantolf (2000). Collaborative learning can therefore create a competitive environment between students in order to motivate them to learn. Hung (2001) confirmed that collaborative learning creates a social learning environment where pairs of students can work together in order to solve problems and gain new knowledge as well as experiences.

According to Liamas-Nistal et al. (2003) collaborative learning refers to an educational approach which involves groups of learners who work together in order to reach common goals. It contributes to increasing students' responsibilities within the learning process in which the success of the learners will depend on the successes of each other. Thus, the collaborative work will be more beneficial due to integration of all the participants' efforts. The concept of collaborative learning is based on the exchange of ideas, experience and skills, all of which contribute to enhancing the interest and critical thinking of the learners. This kind of learning gives students the opportunity to be more naturally sociable through working together to solve problems (Srinivas, 2008).

Thus it can be seen that collaboration offers a number of opportunities for learning. There are social as well as intellectual facets involved and these can therefore stimulate discussion and idea sharing but can also create a competitive environment whereby pairs or even groups of students can become involved in challenging problem solving and develop their critical thinking skills. However, the research examined thus far does not really discuss the extent to which children can collaborate or how their collaborative skills develop with their social and emotional development. This is examined in the next section.

2.4.2 The Ability of Children to Learn Collaboratively

The question of whether young children can learn collaboratively has been the focus of discussion between researchers and there have been differing opinions. Several researchers indicate that children find learning in a collaborative manner intrinsically difficult. Different concerns have been highlighted which can make this process harder and can make it trickier to facilitate for children.

Piaget (1959) stated that children under 7 years old will find it difficult to effectively collaborate through discussion and knowledge sharing. He later went on to suggest that children will be more able to do this from 7-12 years old, i.e. at the stage of concrete (see section 2.3) operations (Piaget, 1977). Vygotsky (1978) pointed out that the social relationships between classmates play an important role in children's learning. Both Vygotsky and Piaget have been in agreement on the importance of social interaction on an individual’s cognitive development.

Children collaborate with their peers of various capacities and ages, and this allows them to perform tasks that are more complicated than they can do on their own. Bierman (1986) further supported this by stating that collaboration and interaction among children who are friends can create a challenging environment which encourages children to help each other.

However, some research promotes the idea of lack of ability in collaboration if the child is too young. Daiute (1985) illustrated that children in the early school years lack the necessary socio-cognitive resources which might allow them to learn effectively in a collaborative environment but the U.K National Curriculum in some areas considers collaborative work as a statutory requirement (McMahon, 1990). Therefore, teachers have been encouraged to support collaborative learning structures, especially within primary school classrooms and these are often designed and furnished carefully to afford this style of learning, with tables grouped together and an area for children to sit together on the floor and engage with activities.

The age at which collaboration can take place is therefore an important consideration. Brownell and Carriger (1991) believed that age is a significant factor in collaboration, where children become more able to understand and realise the behaviour of others when they get older. Tomasello et al. (1993) confirmed that a lack of socio-cognitive skills in younger children could prevent them from participating in collaborative learning. However, a study in primary schools by Pollard (Pollard, 1993) confirmed that collaboration between pupils during group work in subjects like mathematics and science contributed significantly to gaining better understanding due to the ability to share and discuss problems together. Thus some researchers believe that primary school children can usefully collaborate whereas others state that young children do not yet have the skills required. The next section will discuss collaboration techniques in the field of mathematics education in more detail.

2.4.3 Collaborative Learning in Mathematics classes

Collaboration through learning involves many aspects, such as social interaction, which can contribute to the success of the learning process, as has already been described. There has been much research in the area of collaborative learning in mathematics. Using small groups of pupils can foster the development of problem solving strategies and related working habits (Sahlberg and Berry, 2002). In particular, collaborative learning within small groups can be beneficial in reading comprehension, mathematics, improved conceptual understanding and achievement in science (Mathes et al., 1997). Fuchs et al. (1998) argued that working collaboratively within small groups may be beneficial and effective for mathematics learning, especially if used with some technological devices. Haller et al (2000) emphasised the importance of collaborative problem solving in mathematics education that enhance the development of mathematical communication and reasoning skills.

Although there are no clear benefits of small group learning on student achievement in mathematics, studies have indicated that appropriate and careful choice of the collaborative learning group would give equal academic achievement among all students, compared to more traditional methods of teaching (DePree, 1998). Creating small learning groups requires more effort than compared with organising large groups of teams or paired-work activities within workshops (Cohen, 1994). To provide the opportunity to work and learn collaboratively requires not just the creation of small groups of pupils but also careful redesigning of mathematical tasks (Berry and Sahlberg, 2006). In doing this, the collaborative learning that takes place can enhance the quality of interaction and facilitate the highest achievement.

Berry and Sahlberg (2006) report on a study of teachers who were asked to provide their views of using small group learning in school mathematics and to give an example of an area of the mathematics curriculum in which small group learning might be used. The results indicated many advantages afforded by the use of small group learning as listed below:

1. Learning social skills. Teachers indicated that working in small groups allows students to obtain some social skills such as learning from each other, teamwork, communication and discussion skills.

2. Learning mathematical knowledge. Different opinions of teachers were reported. Some mentioned that working together in small groups can encourage critical thinking. Another teacher said that reading some mathematics exercises out loud would help students to understand the mathematical concepts. Also, learning within these small groups would build students' confidence through participation in finding solutions.

3. Increased Effort. Students working together will contribute more towards achieving results as opposed to working alone.

4. Changing learning process routines. Usually students receive information from teachers during classes, but small group learning allows students to work together and learn from each other.

The great advantage of collaborative and cooperative learning in mathematical classes is that each student is an important part of their classmates' learning process. Gillies & Boyle (2006) found that teaching by using cooperative learning techniques in a classroom can encourage children to interact and take part in the activities through group discussion. When teachers encouraged children to explain their thinking it helped the children to clarify their explanations and justify their reasoning and problem-solving strategies which helped teachers to be aware of their difficulties and correct any misconceptions. Moreover, the more teachers probed students' explanations, the more explanations students provided; and the more correct and complete these explanations were, the more they were positively related to achievement scores (Webb et al., 2009). Thus a collaborative learning environment in mathematics can allow children to interact and interchange their knowledge, ideas and experiences with each other but it can also help the teacher, by listening to students talking in order to discover what they understand and where they need help. Furthermore, From Crook's perspective (Crook, 1998), children are considered as natural collaborative learners. Bersma and Visscher (2003) added that children enjoy working together through different activities like play. For example, the school playground gives children the opportunity to explore, negotiate, teach and share things between each other (Hyun, 2005). According to Gordon and Browne (2011) Piaget and Vygotsky believe that children's activity through playing is considered a significant factor which contributes to learning. This is due to the enriched nature of the learning environments used wherein the learners have the opportunity to discuss and exchange ideas and beliefs through conversation and asking questions to their peers who are actively engaged (Srinivas, 2011). The next section discusses the connection between collaborative learning theories and educational games in more detail.

2.4.4 Collaborative Learning Theories and Educational Games

According to Leonard (2002) Constructivism is considered as one of the most prominent learning theories which have been utilised within traditional and non-traditional educational fields. Wilson (1995) mentions that learning environments which are based on constructivism theory are considered as social environments where learners work collaboratively in order to support each other through the diversity of information resources and problem solving activities. Educational games enhance communication, collaboration and problem solving skills which are required in learning environments (Pivec and Pivec, 2008). Thus, following this approach of learning will help students to participate actively within a process of learning in order to learn how to solve problems and work collaboratively to reach their target goals. Swan (2005) adds that the constructivist style of learning uses a combination of cognitive and social theories and Ke (2008) claims that educational games have played an important role in fostering active cognitive thinking in players and significantly promoting motivation towards learning.

According to Rust et al. (2005) the notion of social constructivism is rooted in Vygotsky’s psychosocial theory which considers social interaction as a significant part of learning. Social constructivism places emphasis on social interaction among pupils in the classroom and a personal critical thinking process (Powell and Kalina, 2009). It creates an effective method of teaching, where students can benefit through collaboration and interaction between each other. Powell and Kalina (2009) have further described social constructivist theory in terms of scaffolding and collaborative learning. The interaction that occurs between learners and machines during game play creates a learning environment which stimulates students to collaborate and engage in learning activities (Csete et al., 2004). Fretz et al. (2002) confirmed that the process of scaffolding can give children the opportunity to achieve higher cognitive goals which they cannot reach individually without support from knowledgeable adults. Moreover, Quintana et al. (2004) mention that helping pupils to explain their ideas and thoughts is considered as a significant key element of scaffolding. According to Nussbaum et al. (2009) scaffolding enables the provision of a collaborative learning environment where learners are encouraged and facilitated to solve problems. It aims to provide an important means for pupils to prompt cognitive and social interactions through exchanging knowledge and experiences.

Educational games aimed at primary school age children are considered especially useful tools in facilitating teaching and learning as they enable information to be conveyed in a fun manner. Educational games, which are designed for learning, can therefore positively influence several aspects within the learning process such as social development, collaboration and developing problem solving skills (Klopfer and Yoon, 2005). The next section looks at collaboration during mathematics problem solving in more detail, and this is particularly relevant in the research of this PhD to examine the effectiveness of collaboration in facilitating the learning of problem solving.

2.4.5 Collaborative Problem Solving

The problem solving approach within collaborative mathematics activities plays an important role in increasing social interaction among students. It gives students the opportunity to share thinking and discuss ideas and therefore particularly lends itself to collaborative learning environments. The constructivist point of view also emphasises the importance of social interaction among students during information construction and exchange of previous experience (Jonassen, 1991). Ernest (1991) adds that this style of learning could encourage the reflective ability between learners and this is considered significant to all levels of mathematical knowledge. Moreover, it contributes to increasing the confidence of students by providing and developing ideas and different concepts between them (von Glasersfeld, 1991). Olivier et al. (1990) stated that learning mathematics using collaborative problem solving techniques centres on students' ideas and information developing between them when they participate. However, this kind of learning needs to be monitored by an individual such as a teacher. Consequently, the construction of mathematical knowledge depends on the individual and the groups which can be achieved through social activities and the teacher's role in this. Therefore, collaboration in mathematical problem solving has great potential value for helping children to relate their developing understanding of mathematical ideas to the everyday world provided it is overseen by a teacher in the right way. In light of this research, many schools have followed problem solving strategies in their classrooms (Lovitt, 2000; Anderson, 2003). However, Smith (2004) stated that many young people have still graduated with a deficiency in problem solving skills even though these are considered a significant requirement in any field of life.

Further to this, playing educational computer games collaboratively has been shown to be more effective in enhancing different players' skills, such as numeric skills, when compared with playing individually. This is because each player can be responsible for a specific task resulting in both players having the opportunity to reach the final game goal (Meluso et al., 2012). Therefore, collaboration in educational computer games can contribute to enhancing learning (Van der Meij et al., 2011; Wouters and Van Oostendorp, 2013). The next section will present some cases on collaborative computer games that have been used to teach mathematics at primary school level.

2.4.6 Collaborative Mathematics Computer Games

Collaboration within educational games is an important topic in scientific research (Kirriemuir and McFarlane, 2004). Oblinger (2004) confirmed a number of reasons for the use of games as significant tools in the learning environment:

1. Games can support multi-sensory learning styles by using different kinds of activities, experiments and problem-based techniques.
2. Games can encourage players to apply their prior knowledge and information which has been previously learned in order to advance.
3. Game feedback enables players to test hypotheses, learn from their actions and learn by doing.
4. Games give the opportunity to the players for good self-assessment through the mechanisms of scoring and reaching different levels.
5. Games can create a social environment which involves communities of players who like to play together and help each other.

Ke and Grabowski (2007) examined the effects of the use of adventure games (ASTRA EAGLE) on 5th grade students (9-10 years old) that were assigned to three groups: cooperative game playing group, competitive game playing group, and no game playing group for four weeks. According to their findings, in terms of mathematics performance there was no significant difference in maths performance between cooperative and competitive conditions and both conditions performed significantly higher than the control group. According to Ke (2008) a study that examined the effect of educational computer games versus traditional paper-and-pencil drills on the maths achievement of 487 5th grade students resulted in no significant advantage of the game in achieving the learning outcomes although it was shown that using the computer game can motivate children more than traditional methods. Playing computer games collaboratively can stimulate learners to explicate their knowledge, however studies on collaborative games have shown that they do not always allow knowledge to be exchanged in order to show the predicted beneficial effect in enhanced learning (Albers, 2008, Van der Meij et al., 2011). Some researchers do not agree on the benefits that collaborative game play can have over individual game play because of their inability to support the expected educational value, and the effectiveness of engagement and learning remains limited (Young et al., 2012). There is still limited research on collaborative game-based learning (ter Vrugte et al., 2015). Thus, further research is needed to determine exactly what should be included in a collaborative game in order to promote engagement and maintain flow whilst providing an environment which teaches problem solving effectively.

2.4.7 Summary

Collaboration gives learners the opportunity to be naturally sociable whilst working together and this sociability enables learners to exchange ideas, experience and skills, enabling their learning to be improved through scaffolding. However researchers differ in their opinions as to what age children can effectively collaborate. Educational computer games have been shown to enhance mathematical skills and so the use of collaborative computer games needs to be investigated and more research is required to determine exactly what would be needed in a collaborative computer game to promote learning of mathematics problem solving in Key Stage 2 pupils.

The next section outlines the key findings and challenges that have arisen from the literature reviewed here (see figure 2.1) and these are then mapped onto the work presented in the remainder of this thesis (figure 2.2).

2.5 Key findings and challenges identified from the literature

Figure 2.1 below shows a number of findings and challenges that have arisen from the literature review. These focus on the theoretical concepts of learning mathematics, problem solving, serious games and collaboration.

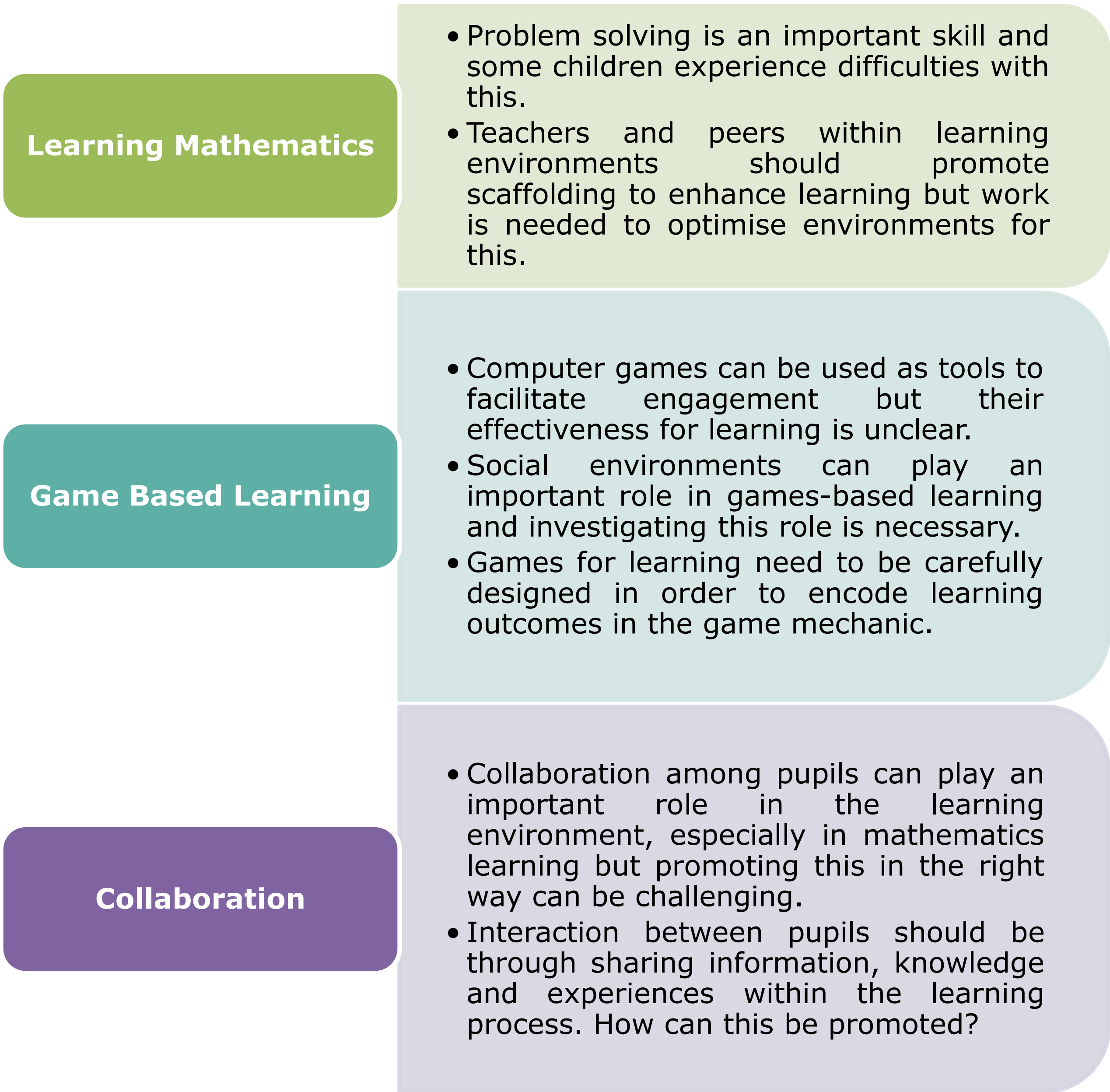


Figure 2-1: Challenges identified from the Literature

As discussed earlier, there are conflicting views of researchers regarding children's abilities to collaborate. The question for this PhD, therefore, is can children in primary school collaborate effectively and, if so, what tools might facilitate this process? Learning mathematics and, in particular, problem solving can challenge some pupils and this PhD focuses on the role that collaborative environments could play in this and how those environments might be made more effective. Evidence suggests that computer games can provide a useful collaborative learning environment but, again, there are a number of opinions as to what makes an effective learning environment as this is still limited in the field of research. Playing computer games collaboratively is not as simple as putting a student in front of a computer and expecting substantial interaction or achievement of results to reach a common goal. Computer games need to be designed with careful attention to incorporate the most important theories of collaborative learning including metacognitive reflection on the learning and consideration of the interaction between learner and game environment. Thus, the main purpose of this study is to examine how mathematics computer game mechanisms can be designed to promote collaboration, and the role of collaboration through playing computer games in supporting mathematics problem solving effectively. The challenges outlined in Figure 2.1 are therefore mapped onto the work conducted in this PhD in Figure 2.2 below.

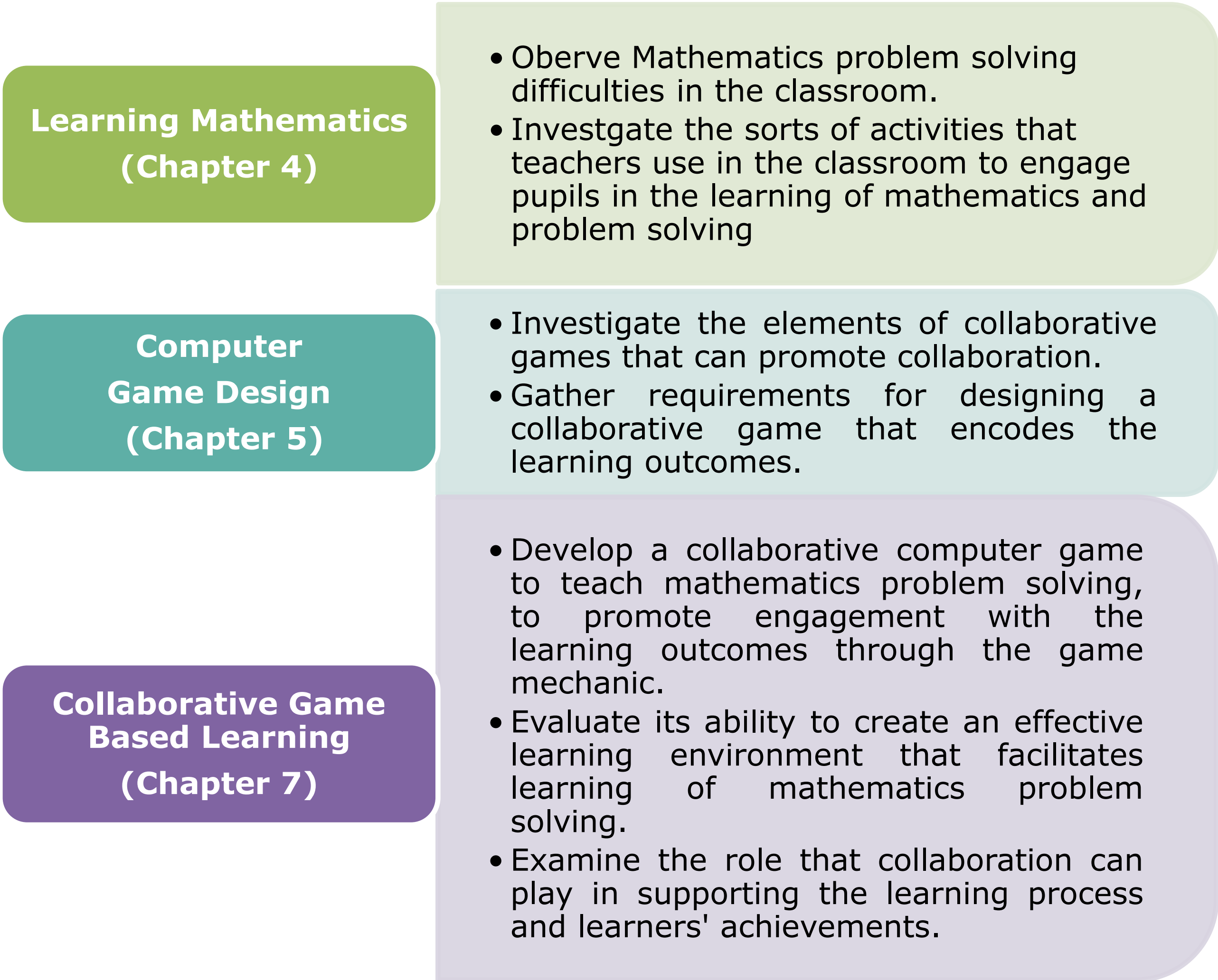


Figure 2-2: Mapping the Challenges Identified to the Plan of Work

2.6 Summary

Mathematics is a particularly important subject which is core to children's education and it stimulates children intellectually on a number of levels. Problem solving has been highlighted as a significant part of this and difficulties with problem solving need to be considered more in learning environments.

Difficulties in mathematics are not uncommon and, in particular, some children find problem solving in mathematics challenging. Educational games have been used widely in supporting learning mathematics and these can promote engagement and achievement. Researchers argue that engagement in the learning environment is vitally important for learning and games-based learning has been suggested in the research literature as a potentially useful approach in teaching mathematical skills. The research discussed so far is strongly suggestive that the use of serious games in the classroom, particularly at primary school level, can be beneficial to learning. It also suggests that appropriate games should include elements of fantasy, challenge, complexity and control and those games should provide clear rules, goals and feedback.

Researchers also propose that collaborative game-based learning motivates children to learn, improves cognitive skills and enhances communication, collaboration and problem solving skills. Children learn by making sense of the world and building this into their existing knowledge. Their behaviour can be influenced externally through the presence of external stimuli or through sharing knowledge and discussing experiences with other learners in a collaborative learning environment. Learners can construct and increase their knowledge within collaborative learning environments and teachers and/or other peers can support the learning process through shared engagement in tasks and interacting with others. However researchers differ in their opinions of what makes a good collaborative environment. This PhD focuses on the role that collaborative computer games could play in supporting mathematics problem solving in the classroom, and how this can facilitate overcoming maths difficulties and enhance the learning process. In doing so, this thesis moves on to begin to address these through a series of studies as described in Figure 2.2. The next chapter will discuss the methodology of this PhD in more detail.

3 Methodology

3.1 Introduction

This PhD investigates the effectiveness of collaborative games in engaging primary school pupils in the process of learning mathematics problem solving. A number of areas requiring further exploration were identified from the literature review in Chapter 2. The findings showed that whilst mathematics is a core part of the curriculum and requires skills that are valuable in life as a whole, for some children learning mathematics and particularly problem solving can be very challenging. It was found that whilst collaborative environments offer benefits to pupils' learning due to their more engaging nature and that computer software can be a useful tool for this, there are differing opinions in the research literature as to what makes a learning environment effective. Games have been used for this but again, opinions differ in terms of whether games should replace traditional teaching in the age of the Digital Native, or whether they should be used in combination with other teaching methods and with appropriate teacher-centred direction. The design of computer games for learning in terms of game story, game contents and how the learning outcomes are encoded in the game mechanic is very challenging and researchers have argued differently about what is important to include in a learning game and the importance of correctly encoding learning outcomes in the game mechanic. This research has therefore led to a number of research questions which were stated in Chapter 1. This chapter presents an outline of the plan of study and the different research methods which have been used in this PhD. In doing so it describes the User Centred Design (UCD) approach used (section 3.2) and the research methods that have been used in carrying out the three studies (section 3.3). The choice of data analysis depends on the data gathering methods used and this is discussed in section 3.4. Finally, working with children presents its own challenges and these are discussed in section 3.5. Each individual study is then described in more detail in terms of the procedures used, participants, findings and analysis in the following chapters (Chapters 4,5 and 7).

3.2 Research Approach

A User Centred Design (UCD) approach has been adopted throughout the course of this research due to the importance of including the user in the design of the system being developed (Lewis, 2006). UCD involves the user in every stage of the design process; in planning, collecting the requirements and testing (Pagulayan et al., 2003) and it is critical in ensuring the system developed is appropriate for the user needs and purposes (Gould and Lewis, 1985; Pagulayan et al., 2003). This is particularly important when designing for children (Hourcade, 2008) who have different needs from adults and therefore should act as informants throughout the design process in order that the researcher might effectively capture the way that they see the world and how they will use the system within it (Fails et al., 2013).

The studies in this thesis needed to investigate the current problem thoroughly before designing with the users' needs in mind. In doing so a mixed methods approach was taken (Johnson et al., 2007). Using mixed methods enables a more comprehensive understanding of user behaviour (Morse, 2003), which can be further enhanced by qualitative supplemental studies if required (Creswell et al., 2003) to give a deeper understanding of quantitative findings. A researcher therefore combines elements of both qualitative and quantitative methods such as interviews, focus groups and questionnaires in order to triangulate data and give a deeper understanding of the situation. This approach is especially appropriate in this PhD due to the relationship between learning, social behaviour and science (Bergman, 2008) and so is relevant for learning in education and social contexts (Teddlie and Tashakkori, 2009).

3.3 Research Outline

This PhD involved three phases of study which are discussed in more detail in chapters 4,5 and 7. In this section an overview of the research studies is given in terms of the methods used within each. The three studies are illustrated in Figure 3.1 and Table 3.1.

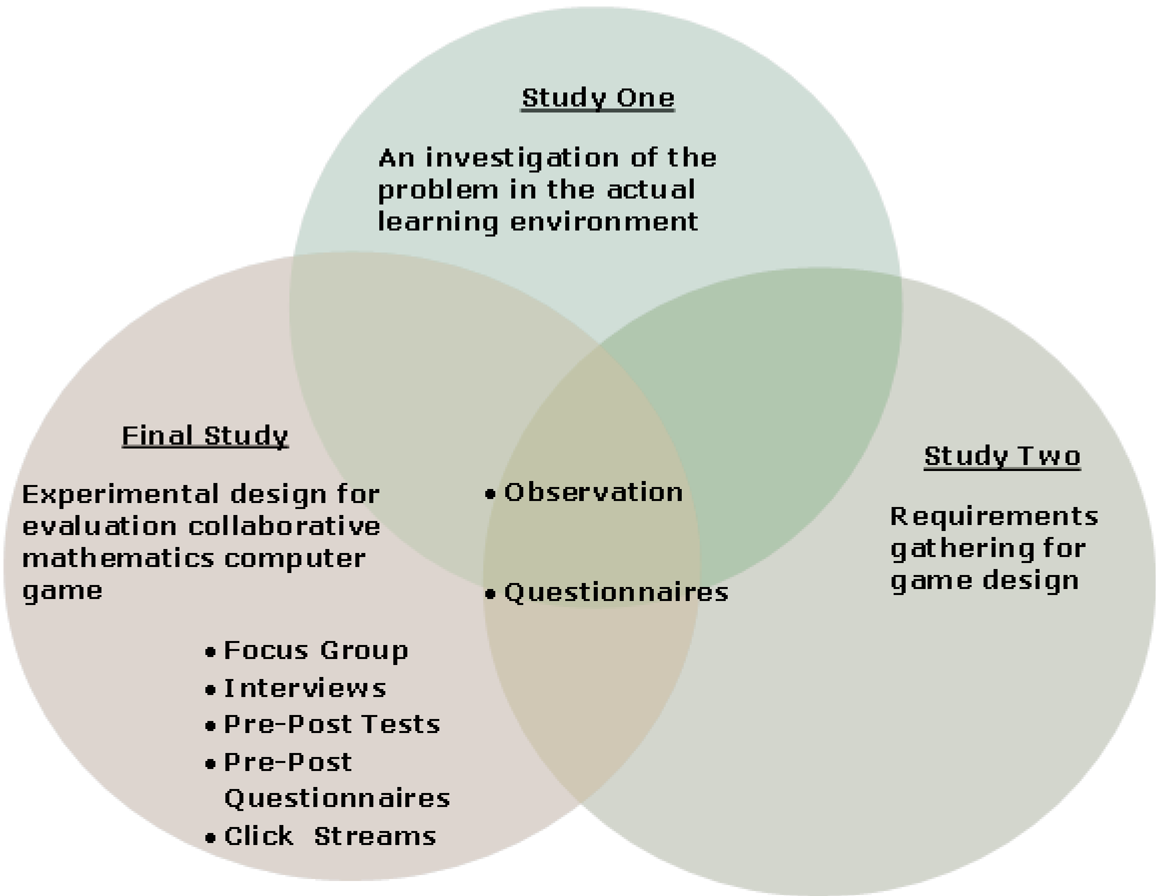


Figure 3-1: Research Design

Study	Study Setting	Methods (pupils)	Methods (teachers)
One	School A	Observation /Questionnaire	Questionnaire
Two	School B	Observation	
	School A	Questionnaire	
Final	School A	Observation/pre-post Questionnaire/ pre-post-test/Focus group/ click streams	Interview

Table 3-1: Research Methods

As can be seen in Figure 3.1 and Table 3.1 above, a number of methods were used in the three studies, namely observation, questionnaire, interviews and focus groups. Further to this pre- and post- questionnaires and tests were used to identify levels of confidence, engagement, motivation and mathematics ability within the game evaluation sessions. Two different schools were used in the data collection and methods used varied between pupils and teachers as appropriate. Table 3.1 therefore illustrates the school setting for each study and types of data collected from pupils and teachers. The purpose of these was to look for evidence of mathematics learning and enhanced confidence and engagement in using the designed game. Furthermore, click streams were recorded and analysed to allow interpretation of game use. These are detailed further in the next sections.

3.3.1 Observation

This method was used in each of the three studies. Observation involves watching and listening to events that occur in environments in order to record qualitative information about what is happening (Thomas, 2003). Observations are carried out at all stages of the design process from the early stages where users are observed using existing systems/environments, and requirements are gathered, through to later stages where use of developed systems is studied. In order to achieve the aims of this PhD observing the learning environment and recording pupil behaviours was paramount.

Hand-written notes and audio recordings were used to record the observations. The audio recordings were transcribed for analysis. The observations were then thematically coded as described in the next section.

3.3.2 Questionnaire

Questionnaires were used throughout the three studies to gather both quantitative and qualitative data. The aim of these was to understand the views of pupils and teachers, the key stakeholders, as is necessary with a UCD approach. Additionally questionnaires are important tools used to expand upon behaviours seen in the observations in order to give a richer data set. This is the mixed methods process whereby a combination of at least one qualitative and one quantitative method can enable the drawbacks of one method to be overcome by the advantages of the other (Bergman, 2008).

3.3.3 Focus Group

Focus groups are another qualitative research method and these were used in the final study of this PhD. Focus groups provide a useful method for evaluating a specific experience or event (Krueger, 1994). They are also particularly suitable for research involving children (Horner, 2000; Horowitz et al., 2003; Gibson, 2007) because they effectively provide a means of interviewing children in a many-to-one environment which puts each child more at ease. Focus groups seek to provide richer information regarding participants' thoughts, beliefs and opinions (Mertens, 2010) and are often used in conjunction with other methods such as observation.

3.3.4 Interviews

In this PhD it was important to gather views from both the pupils and their teachers. Semi-structured interviews were used in the final study to gather the perspectives of the pupils' teachers regarding the game design and its use by pupils. Interviews offer a more private forum for giving viewpoints (Gallagher, 2009) and allow the interviewee to be open and candid without fear of others hearing.

3.3.5 Pre-and Post- Tests

In the final study where the game was evaluated it was important to calibrate the progress (or lack of) in pupils playing the game. A pre-test and questionnaire were therefore used to establish the level of mathematical ability, confidence, engagement and motivation as well as to gauge levels of computer literacy of each pupil. Once the game-play sessions were finished, the same test and questionnaire were then used again enabling any change in performance to be recorded.

3.3.6 Click Streams

The final study, where the game was evaluated, also involved the recording of user mouse-presses. The intention here was to examine where in the game each user clicked to select choices and to analyse behaviours in terms of changes of mind and incorrect choices. This type of quantitative data can be useful as an objective set of recorded actions which provides evidence of behaviour. Additionally, these data can easily be recorded using the software itself which makes the collection of this type of data unobtrusive to the participant.

3.4 Data Analysis

Different types of data were recorded in the studies and so different analysis methods were required. The observation, focus group and interview data, being qualitative in nature, provided a rich description of events and activities that took place both in terms of what was said by the participants and their behaviours. Hand-written notes were used to record these methods in chapter 4, 5 and 7. However analysing this type of data required not just a discussion of what was observed but also a method of discretely recording behaviours from the data gathered through thematic coding. According to Braun and Clarke (2006) thematic coding is a transcript method where data are identified and reported as themes. The method involves assigning codes to segments of text in transcripts and then counting instances of these codes to identify themes, thus translating qualitative data into quantitative values (Guest et al., 2012) and allowing easier understanding of trends in the data. Thus observation and focus group data were coded thematically in chapter 5 and 7 to allow the data to be understood and described in more depth. From this trends and patterns could be detected and inferences drawn more easily from the data. This also allows statistical analysis, where appropriate, to be used.

Pre- and post-tests, on the other hand, provided quantitative data from the outset, as did the click streams, and therefore allowed these data to be statistically analysed for significant differences in abilities and behaviour.

The pre- and post-test test data were analysed using the Wilcoxon test in SPSS because the data were non-parametric; the data were not normally distributed and the questionnaire data measurements were taken on an ordinal scale. However, the data were also analysed as percentage changes showing the difference in score as a percentage of the pre-test score in order to highlight any significant differences in individual cases. Click stream data could be easily recorded using the software itself and these data were used to identify patterns in play such as time spent in solving problems and confidence in choosing answers. This was considered useful in illustrating frequencies of different actions during game play.

3.5 Challenges Encountered

Working with children provides its own challenges as access to schools requires finding a school which is prepared to work with the researcher(s) and teachers who can make time for their class to take part in studies given the busy schedule of the school day. Additionally schools are only available during term time and so studies have to be scheduled for and contained within these periods otherwise after school clubs need to be used. Access to children has to be given via a gatekeeper and in the case of the work carried out for this PhD, the gatekeeper was the teacher. There can then be further restrictions on this access such as only being allowed to work with the children when the gatekeeper is present in the room, and this was the case for these studies both in terms of sitting with the children whilst they were observed and also holding focus groups after the observations. Doing so required the researcher to gain a formal criminal record check (DBS) before they were allowed to work in the school and this had to be recorded on the ethics application before the studies would be approved by the School of Computer Science Ethics Committee. The ethics application was also considered high risk, given that children were involved, and so meant providing evidence of additional safeguards being in place for the children.

Consent also needed to be gathered from the pupils' parents. This, in itself, is challenging because consent forms need to be drawn up and sent home and encouraging parents to fill them in is difficult. This can be due to a number of reasons such as the forms getting lost between school and home, forgetfulness or apathy when completing forms or the parents simply not wishing their child to take part. However, no child could take part in the study without their parents' permission and consent forms were completed for each child that took part.

Last, but not least, were the challenges of designing for children both in terms of the system being developed and the experimental design. In such studies there exists a risk that the study could impact a child's future perception of maths in an adverse way. The researcher aimed to minimise this risk through careful design incorporating the teachers' experience and advice and following the U.K. National Curriculum closely. Methods of study were chosen carefully in order to gather data properly representative of the situation and teachers were present and monitoring the study progress throughout. These challenges reinforced the need for a UCD approach from the beginning since children have their own unique perspectives and developing understandings of the world around them and these need to be captured to enable an effective design.

3.6 Summary

This chapter has presented an overview of the methods used in both the data gathering in each study and the analysis of those data. A number of challenges were encountered during the three studies in this PhD and these are discussed and how they were resolved. Chapters 4,5 and 7 present the three studies, respectively, in much more detail. Each of these chapters provides a container for each study and so presents the study design, results and findings which are discussed in terms of how they fit into the overall PhD work. Chapter 6 gives details of the design of the computer game.

4 Study One: The Current Learning Environment

4.1 Introduction

At the beginning of the research, an initial study was proposed to first gain an understanding of the teaching environment, methods used by and problem solving experiences of Key Stage 2 children and their teachers. As such a study involving a representative class of year 5 children, i.e. Children aged 8 to 9 years old, and teachers was conducted. This study, reported in this chapter, used two methods; observation of classroom activities and questionnaires given to pupils and the teacher. The aim of the observation was to explore difficulties experienced with problem solving topics and the questionnaire was to further investigate students' and teachers' views in the mathematics learning environment in terms of problem solving, collaboration, activities done and difficulties found. Therefore, an initial set of objectives were drawn up as shown in section 4.2.

4.2 Objectives of this Study

The main objectives of the overall thesis were outlined in Chapter one. They seek to provide ways of verifying the hypotheses. This study represents Objective 2 from chapter one (see section 1.3). The specific activities of this study were:

- To attend key stage 2 problem solving classes and observe how problem solving is taught;
- To observe behaviours and any difficulties pupils experienced;
- To conduct a questionnaire-based study to determine pupils' views of the mathematics learning environment;
- To conduct a questionnaire-based study to determine teachers' views of the mathematics learning environment.

The study is firstly described in detail in the next section and then the results are presented in order to identify initial requirements for a prototype collaborative game environment. These requirements are then expanded upon in the next study (detailed in Chapter 5).

4.3 Classroom Observation

4.3.1 Introduction

The first stage of the study involved observation of classroom activities in Key Stage 2 problem solving lessons. Observation is especially useful in documenting learning activities and classroom interactions, and here observations of interactions and levels of engagement in activities were important to note.

4.3.2 Method

The observations were conducted on 23 Year 5 pupils (8-9 years old) at a local primary school (school A). They took place twice a week for a period of 4 months. The goal of this study focussed on the types of skills used and activities performed in the mathematics classes and, in particular, looked at the difficulties experienced with mathematics and especially problem solving topics, and the use of collaboration and games to overcome these.

4.3.3 Results

In general children in the classroom were polite and very observant. Teachers moved between tables to help children either with their writing, reading or to assess their work.

Teachers were observed to make use of games in the classroom. At the beginning of each session, teachers played different kinds of games such as number games in order to refresh the pupils' memories. The use of games in the classroom was effective in that it appeared to engage the pupils and provided a fun way of challenging the pupils as can be seen in Case 1 below:

Case 1:

During one of the games pupils stood together in a circle. The teacher started to say "zero" and asked them to carry on by adding 10 to the previous number such as 0-10-20…1110..and then she switched the game backwards to be 1220-1210-……0. She tried to challenge the children by switching the game back and forth regularly. Finally, she switched between just two pupils whilst the other pupils looked on in surprise, and then the teacher told them "I just want to challenge both of you boys".

Different pupils expressed different feelings within the mathematical learning environment. For example, some children felt bored during the maths classes (Case 2) and therefore did not work very quickly whereas others were observed to enjoy the maths sessions (Case 3):

Case 2:

The teachers went around each table to help the children either with writing or reading or to assess their work. Some of the children appeared bored and they did not do their writing quickly. They needed to hear the instructions again at times, and this was due to them not giving enough attention to what had been said from the beginning or not remembering.

Case 3:

Problem:

How many corners and sides are there, and are these sides straight or curved?

Observation:

The children were very active and answered all of the questions.

Not all children felt confident about mathematics, however. For example some children were not forthcoming in putting their hands up to answer questions, even when it transpired that they knew the answers. However, their confidence did grow with more examples and encouragement from the teachers, such as encouraging words and stickers. Different activities were also used to encourage and engage as shown in Case 4 below:

Case 4:

Problem:
Think about 4 different ways to make 5p in each pair of hands.
Observation:
Children started drawing the coins on a sheet. After a while the teacher switched activities to playing a moneybox game with the children. He displayed some attractive money boxes and in each he put a different amount of money. He then asked them at the end how much money he had put in. The children really enjoyed the session because it included lots of activities and incorporated fun as well.

Indeed, it was important and useful to bring the subject alive with real objects and examples (Case 5) and technology was also used to appeal to the children (Case 6):

Case 5:

The teacher gave the pupils a question as a story. She brought some of their toys in to represent the characters in the story and to grab their attention and help them focus more.

Case 6:

Use of the number grid was presented through the smart board and this was observed to be really attractive to the children because when they pressed on any of the numbers the colour of the number changed each time.

Collaboration played an important part in the classroom and the teacher was observed to get the children collaborating in order to help them solve problems (Case 7):

Case 7:

The children were asked to answer a set of questions related to solving number problems. How many different addition sums can you write with an answer of 24? The teacher gave them the chance to solve the first question all together.

Observation

The teacher gave them 0-10 number cards in front of them and to help them make 24 using the number cards. The children were observed trying to find the appropriate numbers by using their fingers and discussed the solution with their partner. Although children loved the idea of the games, however, not all the students were confident with their choices as discussed later.

The children tended to differ, however, in terms of their approach to sharing their work. Some children did not like their writing to be shown to their friends next to them. Other children liked to discuss and compare their answers with others and this enhanced their competition and motivation. It was observed, however, that children worked slowly and with less motivation when they worked alone, so collaboration, whilst not appreciated by some, did provide a positive influence. Case 8, below, shows another example of collaboration between pupils and with the teacher but it also demonstrates the effectiveness of kinaesthetic learning (which can include physical "learning by doing" activities (Fleming and Mills, 1992)) and the use of real examples:

Case 8

Problem:

The teacher started by writing the number of each of two kinds of grape on the board (4 red and 3 green) and asked:

How many more red grapes than green grapes are there?

Observation:

Not all the students gave the right answer; some of them said 4 or 3. Finally, the teacher asked 7 children to stand up to represent the 2 groups of grapes. The first group involved 3 students representing the green grapes. The second group involved 4 students representing the red grapes. Using this method all the children got the right answer quickly. It was very clear from these observations that the children understood mathematics better if they could connect it with reality and daily life.

It was clear that students differed in terms of thinking, analysis and solution-finding. This suggests that enhanced collaboration among pupils may allow them to benefit from each other through the exchange of ideas and collaborative problem solving. The uses of different problem solving methods and of collaboration are seen in Case 9.

Case 9:

Problem:

Three monkeys ate a total of 24 nuts. Each of them ate a different even number of nuts.

How many nuts did each of the monkeys eat?

Find as many different ways to do it as you can.

Observation:

The teacher aimed to make the pupils' methods of solving the problems more logical and systematic. She asked them to try solving this problem by distributing the even numbers in order to cover all the possibilities. One of the students started his solution from the lowest even number to the highest. He therefore told the teacher that the first monkey should be given 0 nuts because it is the lowest of the even numbers. Another student was not sure about this answer and the teacher told him that was a wrong answer and asked him if he could give a reason or an explanation as to why he couldn't give any of monkeys 0 nuts. However, another student noticed that the question stated that each of the monkeys would eat a different even number of nuts and thus it would be impossible to have 0 nuts for any of them.

The teacher then asked them to think about different solutions (and emphasised they needed to be different) and also solutions using odd numbers as well. Some of the children thought about the lowest and highest numbers while others thought about tables, charts and descriptions referring to each monkey. Finally, the students needed to write and explain all the methods they had used and how they started solving their problems.

Some children found it difficult to answer oral questions and at times the teacher needed to write numbers down on the board as well as speaking them aloud in order to help the children understand the questions. In contrast, other pupils were able to give the right answer without any explanation.

The example in Case 10 is known as the Penta Post problem[1]. This type of problem tries to demonstrate the use and importance of mathematics in everyday activities. In doing this problem the teacher tried to help pupils identify how to use arithmetic in practical situations, but it was clear that they struggled with the activity.

[1] Found at http://nrich.maths.org/1133

Case 10: (continued on next page)

The session began with a general discussion about posting mail to see what the children knew about the postal system. The teacher then gave an explanation of measurement and asked some questions related to this, for example:

1. What sorts of things do we need to measure?
2. Who knows what the unit of measurement is?
3. Why do we weigh things?

She gave them an example of baking at home to illustrate the importance of measurement. One student explained why it is important to measure things when baking a cake – that you need to know how much the ingredients weigh and that it will go wrong if not measured. The teacher then introduced the problem in a more engaging way; she gave them an example saying that she would like to send a box in the mail to her sister in London and asked the children what she needed to do. She also asked them about their experience of sending mail. To further illustrate the scenario, she set up a weight activity where pupils had to put weight on a set of scales and conduct measurements. She asked one student to come to the smart board to put some weight on the scales and she asked the rest of the children to face the other way round to make the process more exciting and motivating for them. The student put 56g on the scale and then the teacher asked the others to think about and tell her what two, or even three, numbered weights had been used to give 56g. The teacher then carried on asking them questions about the mail system, for example: "Do you know what I mean by a first class and second class stamp?" Also: "Do you know how to pay for your mail packages?"

Case 10 (Cont'd): Later, she distributed sheets which detailed the problem. She solved the first question with them together on the board. She tried to explain the two postal classes (first and second) that could be used to send mail (the word "first" indicates that the mail will arrive as quickly as it can while second class mail will be like a snail's mail as it will be as slow as snail and will take a long time to arrive). From this observation it was obvious that the teacher attempted to link everything with real life in order to make it as simple as she can for the children to get the information. She later asked them to choose a partner and start discussing the problem and sharing ideas. Most of the pupils struggled with this for various reasons:

- The sheet of paper contained too much information which had not been explained by the teacher;
- The information given contained different numbers and also different units (different prices and different weights in grams);
- These differences were followed by whether the parcels should be first or second class;
- Overall the pupils found this too much information to think about and link together.

Due to these reasons the pupils did not do any calculations correctly and mixed all the numbers and prices due to both their confusion from the beginning and the lack of experience they had had with using the post office. The teacher therefore asked them to come back to the carpet and she explained the process once more to them, but the session ran out of time and they ended up doing nothing to solve the problem.

In lessons the teacher constantly reminded pupils to think in a systematic way in order to solve the problems or find solutions. She advised children to follow the mnemonic *RUCSAC* as detailed in Table 4.1.

Read the question carefully. What is the important information?
Understand the question what do you have to find out?
Choose: choose the right operation(s) and method of calculation.
Solve the problem! Make sure you follow all the steps.
Answer: have you answered the question? What were you meant to find out?
Check your answer if possible; use the inverse to check your working out.

Table 4-1: RUCSAC Details

4.3.4 Discussion

The observation results highlighted a number of key findings which also tie in with the research literature reviewed in Chapter 2. Firstly, some children were observed to struggle with mathematics problem solving in the classroom. For example, some found solving an oral problem difficult without writing it down and others became overwhelmed by the details of certain problems. A number of approaches were used to try and teach problem solving, namely bringing in real world examples and scenarios, bringing the subject alive with toys and activities, playing games in the classroom, collaborative activities and use of technology. Some children enjoyed the subject of mathematics but others appeared bored and instilling a sense of fun was important in the classroom to try and combat this. Activities involving kinaesthetic learning helped with this and clearly also enhanced understanding of difficult problems. Kinaesthetic learning is an active form of learning whereby pupils carry out physical activities rather than passively listening to and/or watching the teacher. Such activities in the classroom involved children actively using tangible objects to work out problems and also included playing number games in the classroom, which were observed to be enjoyed by pupils. Using different kinds of games enabled the creation of an environment for learning where challenge and motivation of pupils were increased, especially for those who tended to get bored with traditional methods of instruction (Al-Washmi, et al., 2013).

It should be noted that not all children found mathematics challenging. This left the teacher with the task of teaching children at different ends of a spectrum of ability, and it is proposed that this provides a strong argument for the role of collaboration between pupils. Collaboration is useful for creating an active learning environment where students are encouraged, motivated and have enhanced ability to solve problems and think mathematically. In the classroom it was observed that even when able to give the correct answer to a problem, often children could not explain in words how they achieved that answer, but during collaborative sessions children were given the opportunity to work through this with each other and to learn to express how they achieved their answers, and many children were observed to respond well to these sessions (Al-Washmi, et al., 2013). Not all children liked sharing their ideas or work but collaboration played a key role in the learning environment and helped pupils at different levels of ability gain a mutual understanding of the topic.

Different methods of problem solving were taught as was the importance of problem solving in real world situations. Rewards were used to encourage (e.g. stickers) and technology also provided an incentive for learning. Stories were often used to capture imagination and add to the fun.

The observations described here were followed up with questionnaires given to both the pupils and teachers. Given the useful information gathered so far it was important to try and expand upon this with specific opinions from children and to get the teachers’ perspectives on the learning environment. This is described in the next section.

4.4 Questionnaires

4.4.1 Introduction

The observations presented several interesting findings of practices which were used in the classroom to teach problem solving and evidence that some children struggled significantly with certain problems. This section details the design and deployment of questionnaires to the pupils and teachers aimed at getting more specific feedback and individual views of the learning environment and activities within it.

4.4.2 Pupil Questionnaire Design

The pupil questionnaire aimed to identify pupil’s views towards mathematics learning, especially with problem solving topics and their view of collaboration within this. The questionnaire had fifteen closed questions, where pupils needed to select either "yes", "no" or "sometimes". These choices were represented as a "smiley face", "sad face" and "neutral face" (see Figure 4.1) in order to provide clarity and encouragement when answering. This is commonly done in questionnaires aimed at young children (Zhang et al., 2002) as it promotes a more meaningful and facilitated response (Eder, 1990; Measelle et al., 1998).

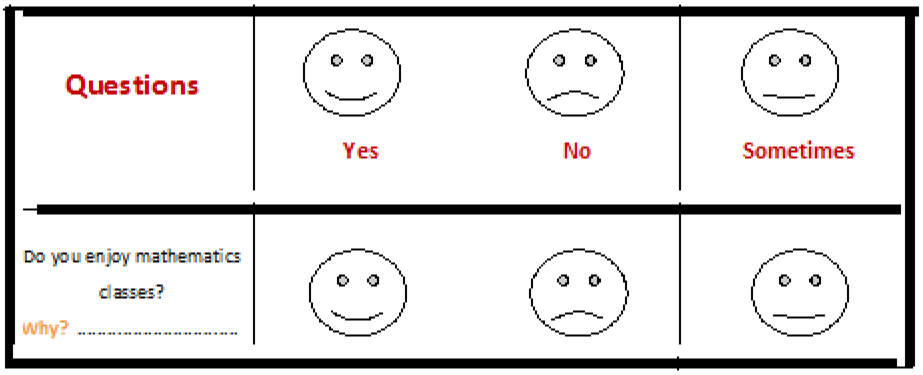


Figure 4-1: Smiley Faces used in Questionnaire

Specifically, questions focused on issues in relation to mathematics classes, problems solving topics, mathematical software or games and collaboration. The aim was to gain an understanding of how maths was received in the classroom (Questions 1-4); the potential influence of educational games, especially in mathematics and in a collaborative situation and their impact on quality of work and learning achievement (Questions 5-8) and the role of the teacher in the classroom (Questions 9 and 10). The last four questions examine views of collaboration. The questionnaire is attached in (Appendix 1).

The questionnaires were distributed to 23 pupils in year 5 (aged between 8 and 9 years old). They were completed in mathematics sessions with the teacher helping them by reading and explaining each question. Pupils took 20 minutes +/- 3 minutes to complete the questionnaire.

4.4.3 Pupil Questionnaire Results

Questions	Yes	No	Sometimes
1. Do you enjoy mathematics classes?	12	1	10
2. Do you find mathematics exercises interesting and fun?	18	0	5
3. In your opinion are you good at maths?	12	2	9
4. Do you find problem solving sessions difficult?	5	6	12
5. Do you play any games in the classroom that involve maths?	15	3	5
6. Does playing the games help you understand maths better?	13	2	0
7. Do you use any computer software in maths classes?	12	4	7
8. If you had this software at home would you use it?	20	2	1
9. Do you like asking your teacher when you are not sure about your solution?	16	2	5
10. Do you look at corrections in your maths work and try them again?	17	4	2
11. Would you like a computer game that helps you to understand maths better?	19	1	3
12. Do you like to discuss your answers with your friends?	7	9	7
13. Do you enjoy to work together with your friends to solve maths exercises?	19	4	0
14. Do you like to share your answers with your friends?	10	6	7
15. Do you think working with your friends will help you to get better at problem solving?	15	4	4

Table 4-2: Pupil Questionnaire Results

Table 4.2 below shows the participants' answers to the questionnaire.

4.4.4 Pupil Questionnaire Discussion

From the table it can be seen that pupils differed in their views of mathematics lessons. Out of 23 pupils around half (12) said they enjoy maths classes, but around half (10) said they only sometimes enjoyed them. One pupil said they didn't enjoy maths lessons. However, more pupils (18) agreed that maths exercises were interesting and fun, with only 5 pupils saying sometimes and none of them saying no. The pupils selecting "sometimes" stated that it depended on the exercises. These two sets of data seem to contradict each other a little but do show that maths is enjoyed by some and not by others which could impact pupils' approaches to learning and the teacher's task of teaching the subject.

Around half the pupils (12) considered themselves to be good at maths, with 9 saying "sometimes" and a further 2 saying "no". When asked about finding problem solving difficult around half the pupils said sometimes and only 5 said "yes". Six pupils stated they did not find problem solving difficult. Pupils therefore seemed to view their skills more highly in the more "generic" topic of maths than in problem solving in particular. Whether this reflects that pupils consider problem solving to be a different domain to maths or whether they don't see a strong connection between the two could be debated. However, it is clear that problem solving is considered more difficult by pupils.

Questions five and six aimed to look at use of games within the classroom and how these might affect students' understanding. Fifteen students stated that they play maths games in the classroom (and 5 that they sometimes play games) and 13 students felt these games can help them gain a better understanding of maths. Two students did not think playing games helped their maths and 3 did not think they played games in the classroom at all. Therefore, mostly pupils were in favour of playing games and agreed that they were useful to their learning.

The majority of pupils stated that they did use computer software to learn maths in the classroom (12 plus 7 saying "sometimes"). The majority also would like to use this software at home. This is unsurprising since the appeal of computer programs and games is high in children and, indeed, many (19) stated that they would like a computer game to help them with their maths. However two students said that if they had maths software at home they would not use it.

Interestingly, most pupils (16) were happy to ask their teacher when they were struggling but only a few (7) were happy to discuss their answers with their friends (a further 7 sometimes discussed answers with friends). However, the majority of pupils (19) stated they like working together with their friends and so seem to be happy to work collaboratively, but perhaps when working alone fewer pupils are then happy to discuss answers. Having reached an answer 10 stated they would be happy to share their answers with friends (and 7 sometimes).

Seventeen pupils mentioned that they like to look back at their teacher's corrections and try to write them out again which is quite a high number. In contrast, 4 students stated not wanting to review their answers.

The final question shows that 15 students considered that collaboration could be useful for helping them to learn to problem solve. Four pupils did not agree that collaboration would help, implying that for some collaboration was not viewed favourably.

4.4.5 Teacher Questionnaire Design

The teachers' questionnaires were conducted on four key stage 2 teachers. This questionnaire aimed to investigate the teachers' views of the mathematics learning environment with regard to pupils' skills, activities and difficulties during the maths classes, especially with problem solving topics. The questionnaire includes twelve open ended questions which focussed on the most significant issues in relation to mathematics classes, problem solving topics, mathematical software or games and collaboration.

More specifically, the questionnaire attempted to get an overview of the actual learning environment regarding mathematics problem solving difficulties, the reasons for such problems, any materials or solutions that have been used recently, whether mathematics classes could be made more fun by gaming, and if students do actually enjoy and interact with each other during collaborative sessions. The questionnaire is shown in Appendix 2.

4.4.6 Teacher Questionnaire Results

The full transcription of answers to the questionnaire can be found in Appendix 3. In this section particularly pertinent comments are reported and discussed:

Q1: What makes problem solving topics difficult for key stage 2?

"Due to the open nature of problem solving tasks and activities children sometimes prefer a definite end to tasks and with finding all possibilities, children become frustrated".

Q5: Is there any solution that you have found which helps problem solving difficulties?

“Teaching different methods of problem solving such as logic, finding all possibilities, and trial and error allows children to choose their own methods”.

Q11: How important is collaboration among children for achieving in maths?

“Talking through a problem is always good problem solving”.

Q12: Do you think collaboration between children would help them with problem solving?

“Yes absolutely, it allows the more able to support those less able”.

4.4.7 Teacher Questionnaire Discussion

Several key findings arose from the teachers’ questionnaire. Problem solving can be difficult for children because the problems are often open-ended and different methods are taught to children and they are also encouraged to try things out when solving problems. Collaboration was cited as being very important because it allows children to discuss ideas and for weaker pupils to gain support from those who are stronger.

4.4.8 Discussion

Many adults consider maths to be a boring, difficult or even terrifying subject to learn (Pietilä 2002; Huhtala and Laine 2004). This has been related to the impact of their negative experience of learning mathematics at school (Huhtala, 2000). Additionally teachers' negative beliefs of mathematics can affect their pupils in the classroom (Gellert, 2000). In this study around half of the pupils considered maths classes to be enjoyable (Al-Washmi, et al., 2013) but it is also clearly difficult for some (Tay Lay Heong, 2005; Al-Washmi, et al., 2013) and many pupils lack the basic skills which are required in order to understand maths (Berch and Mazzocco, 2007).

Mathematics classes create a challenging environment where students have the opportunities to think and search for a problem's solutions. Whilst not all students enjoy maths Kislenko et al. (2007) found that 76% of students still worked hard in mathematics lessons even though they did not enjoy them. However Hoskonen (2007) indicated that pupils enjoy mathematics classes more when doing puzzles to solve problems. It is therefore clear that maths can be viewed very differently by different people.

As far as difficulties in problem solving are concerned, in this study around half of the pupils responding indicated that sometimes they consider problem solving difficult. Teachers' answers regarding problem solving difficulties also confirmed that there are several issues which contribute to this dilemma. There is no set way of solving a problem and different skills must be taught to children so that they can choose the most appropriate way to solve a problem by themselves. According to a report by TIMSS (2008) pupils lack the mathematical skills needed for problem solving. These skills fall into three domains; knowledge, application and reasoning. In addition, language can also be an issue with problem solving. For instance, children can find language difficult to understand within problem solving exercises. Stendall (2009) confirmed that the abilities of students to think logically and use memory effectively in order to give a good explanation for their work which is meaningful are important factors in learning skills and solving problems. Children can struggle to explain what they have done and how they found a solution (Al-Washmi, et al., 2013).

Various activities can make mathematics more enjoyable. Research has indicated the importance of task interest within the learning environment (Cleary, 2006) and interest in maths activities can be related to people's intellectual and social characteristics (Thomas, 2010). For example, a study by Smith (2011) showed that children found mathematics interesting and the pupils tended to do well in maths when they had the opportunity to play games in their maths classes to make them more engaging.

It is interesting that Estallo (1995) indicated that people who play games have more developed intellectual skills than those who don’t. Playing games within a learning environment can create a new learning culture where students learn better through their habits and interests (Prensky, 2001). There is evidence that involving games within the learning environment may enhance deep learning (Oblinger, 2004) and Prensky (2007) purported that games can change the way that students perceive and interact with the learning environment, both physically and socially. Lenhart and Kahne (2008) discuss the attractiveness of games and how they can sustain attention for long periods of time. In many previous studies teachers have utilised and applied games as an important part of everyday classroom teaching (Futurelab, 2009; Groff et al., 2010).

In this study 65% of students indicated that they like to play games within the maths classroom and 57% felt that playing games would help them understand better (Al-Washmi, et al., 2013). Likewise teacher's answers indicated that involving different kinds of games within the learning environment would engage pupils in problem solving. They also mentioned that some students need physical interaction for their learning, so games would help them, and this was observed in the classroom. It is also important to have a good choice of teaching methods in the learning environment in which games are involved (Al-Washmi, et al., 2013).

However, whilst results in this study have indicated that children do like to use games when learning maths, there are also children who prefer a hands-on approach and they enjoy moving around the classroom and manipulating resources (Al-Washmi, et al., 2013). It is clear that the kinaesthetic approach is important in the learning environment and this is something that can be reinforced through the use of games.

In terms of involving teachers in the learning process, in this study 70% of pupils liked to ask their teachers about their solutions and they liked to have their answers corrected, and this is also reported by the teachers in their feedback (Al-Washmi, et al., 2013). Teachers play a significant role within the classroom (Crawford, 2000) and interaction between students and teachers through communicating and sharing knowledge plays a role in developing pupils' mathematics ideas (Rosales et al., 2008). Kim and Hannafin (2011) reinforce this idea in saying that pupils who lack adequate prior knowledge like to have a teacher who can scaffold their problem solving learning. According to Hsin and Wu (2011) teachers should involve different strategies of scaffolding within different levels of a child’s understanding.

This study shows that collaboration among students can play an important role within the mathematics learning environment. It was found that 83% of students liked to interact and communicate with each other in order to share information and ask for advice. Therefore, collaboration is considered as key for achievement in problem solving tasks due to the active knowledge construction that takes place (Veldhuis-Diermanse, 2002) and the various activities that can be carried out in a collaborative manner (Al-Washmi, et al., 2013). The teachers' answers confirmed that collaboration among children is important for sharing ideas (Al-Washmi, et al., 2013).

The observations in this study have reinforced the view that in order to create an engaging learning environment, that environment needs to encapsulate fun, stories and games and utilise collaboration within those. Kinaesthetic learning is valuable as is the use of technology and from this it is proposed that collaborative computer games would provide a useful tool to teach mathematics problem solving. Such a game could present a fun interactive storyline to be navigated through and with mathematical problems built into the game mechanic. It is proposed that an environment such as this could be engaging for pupils and therefore provide motivation to learn.

The questionnaire studies further back this up with findings that pupils do enjoy using computer games in the classroom to learn maths and that collaboration is important as it allows pupils to help each other and explain solutions in different ways to each other. This sharing and discussion of problems can be particularly helpful for those who have difficulty in mathematics.

This is also in accordance with research which shows that the performance of children who work collaboratively will be higher than children working individually (Underwood et al., 2000). Additionally collaboration can benefit children of different ages (Hogan and Tudge 1999), mixed ability groups (Garton and Pratt 2001) and groups with children who have different levels of confidence (Tudge et al. 1996), motivation (Gabriele and Montecinos 2001) and are of different gender (Strough et al. 2001). In fact, collaboration helps students to gain new experiences of working together to solve problems within a team and this experience may also help pupils to work efficiently in future collaborative learning projects.

4.5 Summary

This study has examined the teaching environment, methods used and problem solving experiences of both children (aged 8-9) and teachers in a UK Key Stage 2 classroom. It was observed that some children did indeed face difficulties when solving mathematical problems but not all children found mathematical problem solving challenging. Pupils engaged differently when learning mathematics; some pupils engaged more quickly than others who were observed to work slowly without any enthusiasm. This could be due to different aspects such as boredom, lack of confidence or lack of reasoning skills. For example, it was noticed that some pupils were unwilling to answer questions in class even when they knew the right answer due to reduced confidence. On the other hand, some children were able to give correct answers but unable to explain the reasons for their answers. Teachers have a significant role to play through scaffolding and encouraging pupils with rewards and incentives which can help to overcome this.

Findings from the study indicate that in order to create an engaging learning environment that encourages collaboration it should incorporate elements of fun, interactive stories and incorporate mathematical problems in the game mechanic. Use of technology to do so will also promote kinaesthetic learning. As such, the study has fulfilled Objective 2 (Chapter 1, section 1.3). The next stage of this research, therefore, is to identify how to make a computer game engaging and what aspects are required to promote collaboration in the game play

(Objective 3). This is presented in the next chapter which describes the second study; aimed at investigating what encourages collaboration and engagement and drawing up a set of requirements for a collaborative computer game to teach problem solving.

5 Study Two: Gathering Game Design Requirements

5.1 Introduction

As we have seen in Chapter 2 collaboration within the game is a key component for learners as it can boost motivation for learning while enhancing game performance (Wood et al., 1976; Walqui, 2006). Effective collaboration can link between learner capabilities and goal expectations, helping students internalize knowledge from interactions with scaffolds while independently achieving their goals.

In this chapter the research therefore now focuses on whether and how playing computer games in a collaborative environment can benefit children in terms of development of their problem solving skills and enhancing motivation and engagement which are so important in the learning environment. In particular the research aims to find out what aspects of collaborative computer games encourage that collaboration, and what aspects motivate and enhance engagement. In order to do this two main methods have been used: observation of children playing a collaborative computer game and questionnaires given to those children to ask about their experiences. This user-centred design approach was aimed at gathering a specific set of requirements for the design of a collaborative computer game that teaches problem solving in mathematics. These requirements are presented at the end of this chapter.

5.2 Experimental Design

This study involved three different experiments which took place at two different primary schools (A and B) with children aged 7 to 10 years old. The experiments aimed to involve children of different ages, gender and in different environmental settings in order to try and gain a representative sample of children in environments familiar to them. In order to investigate elements of collaborative computer games that encourage collaboration, motivation and engagement an appropriate computer game needed to be chosen.

The research reported in Chapter 2 demonstrated that the most appropriate game genre is adventure and that it should have collaborative social elements, an interactive storyline and clear goals and rules. Lowrie (2002) indicated that construction toys such as Lego provide opportunities for game-play contexts which stimulate mathematical thinking. These games are designed to use spatial abilities and are popular with children, parents and teachers and so are considered helpful tools in education (Liao and Ho, 2011).

LEGO® Harry Potter is an example of a commercially available computer game which uses Lego-inspired scenes and characters but also the Harry Potter character and story which is particularly popular among children. In addition to this it has strong collaborative features and children are required to solve different puzzles to progress through the game such. It also aims to provide an element of adventure and fun through the use of magic. For these reasons, LEGO® Harry Potter: Years 5-7 was chosen for use in the experiments. Children were grouped together in pairs and played LEGO® Harry Potter for sessions lasting 25 minutes. Each group used an Xbox 360 with output to a TV screen. The game allowed a split screen view so that each child could follow what their own character was doing as well as the character of the child with whom they were collaborating. For one experiment two groups took part at a time with two Xboxes located next to one another in the room. This allowed collaboration to take place between the groups as well as within them. Table 5.1 illustrates the experimental design and also shows the number of participants who took part in each experiment and the schools that were involved (see also Table 3.1, Chapter 3).

Experiment Design	**Experiment One (School B)**	**Experiment Two (School B)**	**Experiment Three (School A)**
Methods	Observation	Observation	Questionnaire
Type	Competition	Non-competition	Non-competition
Setting	Holiday (School Club)	After school day	During school day (lunch time)
Participants			
Number of Groups	Three Groups	Nine Groups	Fifteen Groups
Gender and total number of participants	Boys (Six)	Mixed Gender (Sixteen boys and two girls).	Mixed Gender (Fourteen boys and sixteen girls).
Age Range	8-10	7-10	8-10

Table 5-1: The experimental design

In the next section experiments 1 (competition state) and 2 (non-competition state) are described. Whilst these were two different experiments conducted at different times they were procedurally very similar and so are presented together in terms of procedure and participants used. The following section then presents the results of both experiments in one table (Table 5.2) so that comparisons can be made between the competitive experiment and the non-competitive experiment. The discussion then focuses on both and makes comparisons between the two.

5.3 Experiments 1 and 2

5.3.1 Participants

The observation was conducted on six pupils in the first experiment and eighteen pupils in the second experiment. Both experiments were done at a local primary school (School B). The majority of participants were boys who showed greater interest in taking part compared with the girls. This difference in interest could have been due to the type of game being played or lack of interest in computer games generally. This is discussed later on in the chapter.

In the first experiment there was a reduced number of participants of an age suitable for this study. This was because this experiment was conducted in the school holiday club during the Easter holiday and limited children attended. Pupils were aged between seven and ten years old.

5.3.2 Procedure

Children were observed in terms of their interaction with game content and with each other, both with the other player and with those observing, and how these contributed to motivate pupils to complete tasks and reach desired goals. The two experiments differed in terms of the presence (experiment 1) or absence (experiment 2) of competition between groups. This was done to enable the researcher to assess the effect of competition on interaction within groups, between groups and with the game-based tasks.

The first experiment was carried out as part of a competition among groups of children in an After School Club, which doubles as a Holiday Club in vacation times, in the Easter Holiday. This was planned in order to encourage children to be involved in the study. Children were divided into three groups in order to play LEGO® Harry Potter (Xbox 360 version) for 25-minute sessions. Each group involved two students. Participants were told that each group would start from the beginning of the game and that the winning group would be the group which progressed furthest through the game. The game participants began playing at the first level (Order of the Phoenix) which involves six sub-levels. The reason for starting at level one was that the time available for play did not allow for more than one level to be played and not all children were equal in their experience of playing Xbox. The duration of the study was for three days with one group each day.

The second experiment was conducted at the same school (School B) in (After School Club) at the end of the school day. The duration of this study was for one month with two groups of two children each per week and three groups for the last week.

Each group was observed for 25 minutes at a time playing LEGO® Harry Potter.

Children in both experiments varied in terms of their experience playing X-box games in general and the LEGO® Harry Potter Game in particular. Also knowledge of Harry Potter as a character from movies or book stories was mixed among the children. For example, some players had previous experience playing games through the X-box device but it was the first time they had played the LEGO® Harry Potter Game. However, they knew the Harry Potter character through reading Harry Potter storybooks. The girls had some experience of playing games using the X-box device, for example Sonic was one such game that they mentioned. However, they had not played many X-box games and it was their first time playing a problem solving game.

Hand-written notes and audio recordings were used to record the observations. The audio recordings were transcribed for analysis. The observations were then thematically coded as described in the next section.

5.3.3 Results

In this section the results are presented in terms of the thematic analysis, shown in Table 5.2. For some observation notes and thematic analysis the reader is referred to Appendix 4.

A set of codes was developed using the observation data. These codes are shown in Table 5.2 and are split into themes: Motivation (M); Engagement with each other (EO); Engagement through the game (EG) and Engagement with the game mechanic (EM). Coded behaviours in the EO theme equate to collaboration between players and observers, and coded behaviours within the EG theme can equate to interaction or they can simply equate to engagement through the game (e.g. game characters, knowledge, experiences and tasks), depending on the coded behaviour. These themes were developed since the purpose of these observations was to identify elements of the game that promoted collaboration and motivation to play the game and also engagement, which can result from motivation. Engagement with the game mechanic was also important since this ultimately will be key in the final learning tool developed for this PhD. The motivation theme incorporates coded behaviours, both positive and negative, that illustrated motivation (e.g. excitement, challenge, aggression, copying). The results of Table 5.2 are discussed in more detail in the next section where many cases are presented.

In the table, certain frequencies are highlighted where they are considered notably different. With discrete data the minimum possible change in the input data is plus or minus 1. For observations where the ratio of the two states is less than 3 a variation of plus or minus 1 in the observed data will produce a large variation in the frequency data and the ratios. Therefore they are not considered to be as reliable as those where the ratio is 3 and above where a variation in the input data would lead to very small changes in the final ratio. Therefore, a notable increase in frequency is considered to be that of 3x or higher.

Code	Meaning	With Competition No. of Occurrences	Without Competition No. of Occurrences	With Competition Frequency Per Player	Without Competition Frequency Per Player	Frequency Ratio: With to Without	Frequency Ratio Without to With	Competition Producing Notably More Frequent Occurrences
co	Collect objects	7	3	1.17	0.17	7.0	0.1	7x
m	Manipulating objects	4	15	0.67	0.83	0.8	1.3	
g	Gesture	4	1	0.67	0.06	12.0	0.1	12x
j	Joint manipulation	4	2	0.67	0.11	6.0	0.2	6x
c	Conversation	5	4	0.83	0.22	3.8	0.3	3.8x
i	Instruction	8	17	1.33	0.94	1.4	0.7	
s	Sharing knowledge	10	22	1.67	1.22	1.4	0.7	
q	Questioning	3	10	0.50	0.56	0.9	1.1	
d	Disagreement	1	1	0.17	0.06	3.0	0.3	3x
arg	Arguing	3	3	0.50	0.17	3.0	0.3	3x
e	Enthusiasm	6	16	1.00	0.89	1.1	0.9	
p	Physical movement	2	5	0.33	0.28	1.2	0.8	
go	Goal seeking	5	4	0.83	0.22	3.8	0.3	3.8x
di	Discovery	7	5	1.17	0.28	4.2	0.2	4.2x
im	Immersion	2	2	0.33	0.11	3.0	0.3	3x
w	Withholding information	1	0	0.17	-	-	-	
cp	Competition	1	0	0.17	-	-	-	
cn	Concentration	1	5	0.17	0.28	0.6	1.7	
f	Fun	2	7	0.33	0.39	0.9	1.2	
ag	Aggression	0	5	0.00	0.28	-	-	
ch	Challenge	0	3	0.00	0.17	-	-	
cy	Copying	0	2	0.00	0.11	-	-	

No of participants	6	18

Table 5-2: Observation Thematic Analysis

5.3.4 Discussion

Playing a computer game cooperatively can provide an opportunity for children to gain many skills and habits that contribute towards building their confidence and which can enhance their effective participation within the group. Playing LEGO® Harry Potter collaboratively created a social environment that encouraged the children to interact and cooperate with each other.

The observation coding shows that the pupils engaged with the game and in collaboration during the game play, and that they were also motivated to play the game. In this section, the observational notes are discussed along with the results of the coding process. The discussion is divided into the themes identified in the thematic analysis.

5.3.4.1 Engagement through the Game (EG)

The design of the LEGO® Harry Potter Game was detailed and contextually accurate, providing a rich backdrop for the action. The game scene involved a playground which was covered in fun toys to play with, for example a swing set, the "teeter-totter", a trampoline and a large slide. There were objects to join such as a jungle gym requiring Wesley's "sticky trainers", and a pet to dig up the sand pit. There were also lots of objects to collect such as "studs" which could be used to unlock new characters with the ability to open up previously locked areas and enable the game to be won. The thematic analysis in Table 5.2 shows that children collected objects with 12 times the frequency in the competitive experiment than the non-competitive experiment, and this activity was higher at the beginning of the sessions.

Moreover, children showed collaboration through jointly manipulating objects with a frequency in the competitive experiment of 6 times that in the non-competitive experiment. This was also apparent throughout the observation when children were collaborating and engaging through the game and/or with the game mechanic by using magic to collect, move or rebuild objects. The evidence for pupils' engagement through the game and with the game mechanic (by collecting objects and joint manipulation) can be seen in cases 1 and 2 below:

Case1: The player spoke loudly "I know there is something we need to collect around here" and then he gave an instruction to his partner: "Jump over here and put these parts together".

Case2: The first player asked his friends "What does he need to press in order to repair the blue car?" His friends said "You need to change characters to Wesley, and then hold the B button in order to fix the cars".

Furthermore, children showed interaction through the interface by gesturing to certain objects on the screen and that can be seen in case 3 below:

> **Case 3**: One of the boys who was standing around the group said:
>
> "There is something on the ground here, look" and he moved closer to the screen and indicated to the screen with his finger pointing to the stick on the ground.

These kinds of gesturing behaviours were seen 7 times more frequently in the competitive experiment than the non-competitive experiment. Immersion was less affected by the competition condition but behaviours exhibiting immersion were still 3 times higher in the competitive experiment than the non-competitive experiment.

In both experiments children demonstrated their engagement through the game with body language and physical movement (this was considered to be an indicator of engagement through sub-conscious means) but the frequencies were very similar in both conditions. For example, some children danced in front of the screen and vocalised, at times mimicking some of the game characters (such as animals' voices). Case 4 below shows evidence for players' enjoyment.

Case 4: Player W said "I love this level."

Researcher: "Why?"

Player W said "Because I can have lots of fun by changing characters to animals such as a cat or an owl in order to enter the pipe, so I like it" at the same time the second player rode the car and sang "Where do we need to go?"

The players interacted a lot with the game tools and characters and had lots of fun and enjoyment discovering things, as was evident by their behaviours reported in Case 5. Fun was coded with a similar frequency in both experiments.

Case 5: Player W: "What is that?"

Player W: "Is this Lego Harry Potter?"

Researcher: "Yes"

Player W: "Ohh, I have never played it"

Researcher: "Do you like to play?"

Player W: "Yes, of course"

Researcher: "Why do you like Harry Potter Lego Game?"

Player W: "I like it because it's funny"

Researcher: "Why do you think it's funny?"

Player W: "Because you can smash things around you in the game and you can fly"

The observations indicated that the competition may have helped to encourage children and their friends to interact through the game initially, but once the players in the non-competition groups started to engage with the game mechanic in order to solve the puzzles, the collaboration and observed levels of engagement appeared to be at similar levels to the competition group. Therefore the competition factor encouraged interaction with the game at the start but was less important for players' motivation as the game progressed.

There was observed to be a noticeable difference between genders in terms of enjoyment when playing LEGO® Harry Potter where boys appeared to enjoy it more than girls. This is discussed further at the end of section 5.3.4.5.

5.3.4.2 Engagement with the Game Mechanic (EM)

The game's environment provided materials to work with and collect and presented an attractive atmosphere for children to be engaged with the game mechanic through building puzzles and solving problems to complete each level. At the beginning children were aiming to explore the game and its tools by discovering game tools and characters. This discovery occurred throughout the observations in the competitive experiment with a frequency of more than 4 times that in the non-competitive experiment. There was also an increased frequency of goal seeking in the competitive experiment (3.75 times). It may be that the competition encouraged engagement with the game mechanic more than the non-competitive experiment because the frequency of collecting objects was also higher (7 times).

However, as the game progressed children became more interested in casting spells, which is an integral part of the game play, through discovering and manipulating objects and with a wide range of spells available for unlocking puzzles. Unlocking and completing puzzles allows players to progress within the game. Therefore, the element of competition became less important to the children as they had become engaged with the game mechanic. This can be seen in Table 5.2 where, whilst players collected objects with a 7 times greater frequency in the competitive experiment (7 occurrences), they manipulated objects more in the non-competitive experiment (15 occurrences) resulting in very little difference between the two conditions for object manipulation.

In the non-competition state it was observed that children were more interested in playing the game and solving the puzzles than thinking of the competition between teams. Case 6 shows evidence for players engaging with the game mechanic.

Case 6: "We need to look around and break everything using the hammer, to break through the gate."

So, they moved the trees to see the ingredients that they needed. Once they had found all the ingredients they picked the strength spell to pull the gate.

5.3.4.3 Engagement with Each Other (EO)

It was observed that the game offered no explanation of what was going on in the story, why gold or red bricks had to be collected, why students in peril had to be saved or what the studs were used for. If a player didn't already have an idea of what to do in this game they would be completely lost which could have had a negative effect on the children's interaction and motivation to reach the goals.

The game involved a myriad of side missions, quests and collectibles. The children spent the majority of the game engaged in simple exploration and puzzle solving, with some occasional combat thrown in, in order to solve the tricky sequences of the game. However, those who hadn't read the Harry Potter novels or seen the movies had a very difficult time trying to decipher what was going on in the game and some children were observed to struggle to know what they needed to do to progress in the game and this can be seen in Case 7 below.

Case 7: Player A was trying to continue pressing into the box in order to open it while player C was playing with water and interrupted his friend by shooting the water at him.

Player A: "Please, you need to help - stop doing that and follow the ghost"

Player C: "Why do I need to follow the ghost?"

Player A: "Because he will tell us where to go"

However, those who did know the Harry Potter story or had played the game before were observed to help others in playing the game by explaining what was going on as shown in Case 8 below.

Case 8: Player N: "Do you know this airplane paper is called memo"

Player M: "How do you know?"

Player N: "Because I read the book, actually I am on the last version now".

Playing computer games collaboratively can create a social environment where individuals behave and respond to each other interactively. In Table 5.2 it can be seen that the children engaged in conversation, questions, instruction and sharing of knowledge. The analysis of these verbal interaction codes indicate that conversation among the children in the competitive experiment was nearly 4 times higher than during the non-competitive experiment. Conversations between children involved some arguments and disagreement which occurred 3 times more frequently in the competitive experiment. This demonstrates that, at times, pupils were not comfortably engaged with each other and didn't support each other and perhaps the pressure of the competition enhanced this. An example can be seen in Case 9 below.

Case 9: Player X: "I need you"

Player Y: "Leave it to me then"

Player Y: "I just did it all for you"

Player X: "Because I don't know how to do it"

However, in terms of instruction and sharing knowledge, during the competitive experiment the frequencies were only slightly higher (1.4 and 1.3 times respectively) than in the non-competitive experiment and the frequency of questioning did not differ much between conditions. This indicates that the competition factor within the game did enhance the verbal interaction, but this consisted more of arguing and disagreement rather than instruction, sharing knowledge and questioning. Researchers have proposed that arguments may not always lead to less effective collaboration (Manninen and Korva, 2005). Arguments can be productive in the learning environment when they involve non-aggressive discussion and explanation as they can help pupils to scaffold each other's knowledge, and there were actually no occurrences of aggression observed in the competition state.

Whilst information sharing had a slightly higher frequency in the competitive experiment (1.4 times) than in the non-competitive experiment (0.7 times), as reported above, it was observed that some children did not want to reveal information to those around them watching the game. However, there was good verbal interaction overall during game play as can be seen in Case 10 and Case 11 below.

Case 10: Player G: "When will I have new characters?"
Player H: "It's like every 50 or 100 points you will have new characters."

Case 11: Player D: "I forgot how to change mode."

Player E: "Don't worry we will try to do it together."

Player D: "Oh that's fine."

Verbal interaction is important in collaboration as it serves to enhance a higher level of critical thinking through discussion, thinking and giving reasons in order to reach the desired goals. When children help each other during their engagement with each other and interactions, they are given an opportunity to perform at levels they cannot achieve on their own. Researchers have indicated that interaction between peers during their cooperation with each other can contribute to the development of the children cognitively and social-cognitively when children share information, ideas and discoveries to help each other. This is more likely to be obvious with friends than with non-friends, who are more sensitive to each other's needs and more supportive of each other's thoughts. Thus, cooperation between friends can be more promoting of cognitive and social-cognitive growth than non-friend cooperation.

Collaborative games provide an interactive environment which requires active participants. It gives players the opportunities to collaborate with others which can enhance children's enjoyment and motivation especially if they are friends. The fact that the LEGO® Harry Potter game was seen to promote verbal interaction indicates that an adventure-based game could prove valuable in teaching mathematical problem solving to children.

The process of collaboration during the game play showed that it did contribute to motivating the children to achieve the desired goals such as solving puzzles. Game play can contribute to the development of several skills such as critical thinking and problem-solving (McFarlane et al., 2002). The interaction that occurs between learners and machines during game play creates a learning environment which stimulates students to collaborate and engage in learning activities (Csete et al., 2004). Serious games, which are designed for learning, can therefore positively influence several aspects within the learning process such as social development, collaboration and developing problem solving skills (Klopfer and Yoon, 2005).

5.3.4.4 Motivation

Motivation is discussed in this section and has been coded in terms of enthusiasm, copying, challenge, aggression, competition, withholding information, and goal seeking. It was observed that children were motivated to play as Harry Potter's character and found this game experience to be different from other games they had experienced and more exciting.

Children demonstrated lots of enthusiasm through body language and physical movement as illustrated in Cases 12 and 13 below, although there was little difference in frequency between the two conditions.

Case 12: One boy expressed his motivation to play by moving and rocking back and forth while sitting on the edge of his chair and he did not lean back in his seat until the game level had finished.

Case 13: Children were standing too close to the screen and preventing the other children from seeing the game. The researcher asked them "Why are you standing up?" and their answer was "We are used to standing up while playing; we feel more comfortable."

Aggression was not observed in the competitive experiment and only a small amount in the non-competitive experiment. In the non-competitive experiment conversations between children involved some arguments which were conducted in an aggressive manner which could have lead to a reduction in motivation of players to play the game and this can be seen in Cases 14 and 15 below.

Case 14: Player N: "You need to help"

Player N: "Will you do something to help or not?"

Player N: "Following the arrow will not help"

Player A: "I cannot do that"

Player N: "Because you need to listen to me"

Player A: "I did, but I still can't do anything"

Player N: "No you did not because this is supposed to be done by helping"

In Case 15 the player's expression of enthusiasm seemed quite violent:

Case 15: Player S: "I will kill you"

Player S: "I am killing everyone"

Player S: "I am going to kill you"

Player S: "Get out from my way"

The results in Table 5.2 indicate that there was very little difference in challenge between the two experiments. This indicates that the competition within the game may not have challenged the children in the game activities but it may have motivated them to play the game because, as mentioned in section 5.3.4.2, there was an increased frequency in the competition state of goal seeking (3.75 times) and discovery (4.2 times). Researchers have argued that educational games that are based on collaboration and competition between players can increase their learning experience through interaction and this can allow the learners not only to learn from the game but also through other players (Sandford and Williamson, 2005). Therefore having challenge is important, but this may not need to be through explicit competition with other players to be effective.

In addition, collaboration is important to allow learning from the other player and the exploration of ideas. Between the two experiments there was very little difference in withholding information and very little evidence that this took place at all (1 and 0 in the competition and non-competition states respectively). Case 16 below shows evidence of players not wanting to share knowledge with other players but this type of behaviour was not commonly seen.

Case 16: Player M: ”Why did we not do that?”

Player N: ”We cannot, I tried it”

Player N: ”Oh, ridiculous look I found one”

Player N: ”It’s really easy”

Player M: ”Don’t tell them”

There was also little evidence of copying behaviour in the experiments. In this study it was generally observed that the children liked to support each other. They were observed standing around the gamers, sharing and discussing ideas. Therefore, involving other children around the players was helpful in increasing the level of motivation and enthusiasm.

The only increase in behaviour in the non-competitive experiment was concentration which occurred to a slightly higher extent in the non-competition experiment (1.6 times more frequently).

Motivation levels were observed to be different among genders where it was very difficult to persuade the girls to participate in the study and they did not show any motivation to play Harry Potter Lego as seen in Cases 17 and 18 below.

Case 17: Researcher: "Do you like to participate by playing the LEGO® Harry Potter Game?"

Player T: "No, I do not want"

Researcher: "Why?"

Player T: "Because, I do not know how to play"

Case 18: Researcher: "Do you like to play the LEGO® Harry Potter? game"

Player P: "Actually not that much"

Researcher: "Why?"

Researcher: "She takes too long to think and she did not say anything"

Researcher: "Do you think it is difficult to play?"

Player P: "A bit"

Researcher: "Why?"

Player P: "I think it's the sort of game that boys like more, and I am not interested for me to play this kind of game"

Researcher: "Why you think this game is not enjoyable for you?"

Player P: "There are lots of funny things but this game is not really simple like the games that I like to play."

During the observations most of the girls in the After School Club and Holiday Club (School B) did not show any enthusiasm to participate in the experiments. Girls appeared to be especially reticent to play in a group with many of the boys who they considered to be better players. (It should be noted, however, that this reticence was not seen in experiment 3 (School A) (see section 5.4 below) where pupils were brought in to the classroom in pairs during their lunch times and girls showed plenty of enthusiasm to play Harry Potter Lego in the absence of boys.) Boys were observed in experiments 1 and 2 here to be more motivated to play the game than girls by standing around the gamers sharing and discussing tactics based on their previous experiences in order to participate in solving the puzzles.

Several researchers have agreed that console-based digital games are more likely to interest boys than girls and this finding has been stable for a long time (Kaplan, 1983; Griffiths, 1991b; Phillips et al, 1995; Wright et al., 2001). Furthermore, gender plays a significant role in children's choices of game genre; therefore, boys and girls will have different levels of interest in different types of games (Gee, 2007; Unlusoy et al., 2010) and gender can affect how children interact with different game genres (Lowrie and Jorgensen, 2011). However it is interesting to consider the possible effect on the motivation of each sex to engage with a game when the other sex is looking on. This is not something that researchers have tended to examine in the past.

5.3.5 Summary

The process of playing the game collaboratively aimed to encourage children to reach the goals defined in the game as they discovered objects and sought to solve individual problems.

Experiments 1 and 2 focussed on discovering how children might be encouraged to collaborate and what motivates them in playing a game, thus addressing objective 3 from section 1.3. In these first two experiments the children showed lots of collaborative behaviour and motivation to play the game. They also engaged well with the game mechanic (research question 3, section 1.1) as far as playing a commercial game is concerned.

Experiment 1 showed some indication that competition among the children may have increased their engagement with the game mechanic and their motivation to play the game. However, data captured in experiments 1 and 2 were not large enough to make conclusive statements about the effect of competition on the game play. Once the interaction had been more fully developed between the children during game play the children started to think more critically and engage in further exploration and discovery in order to reach the goals and complete the task. This was obvious through behaviours like giving instructions to each other, asking questions and sharing knowledge. Experiment 1 and 2 confirmed that fun, challenge and enthusiasm did not differ much in frequency between the conditions but immersion was higher in the competitive condition. There also was plenty of evidence of enthusiasm to play the game and of the children having fun whilst playing the game.

Experiments 1 and 2 demonstrated that the children observed engaged very well with the collaborative nature of Harry Potter Lego and were observed to collaborate with each other both within and between groups. The collaboration among the children played a significant role in them supporting one another but this may have minimized the challenge that they experienced. This became apparent during experiments 1 and 2 where challenge was not observed to be particularly high or different between the two conditions. However, challenge and complexity need to be incorporated to engage children, but children also need to understand each stage of the game and its goals and requirements and be able to progress through the game. Those that were less familiar with the game found it more challenging in terms of knowing what they needed to do and how to do it.

Experiments 1 and 2 in combination with Study 1 (Chapter 4) have therefore provided the following list of requirements for the learning game:

- Fun
- Collaboration
- Kinaesthetic learning
- Playful environment
- Challenge
- Fantasy
- Clear goals
- Clear rules

However, from these experiments several elements have been highlighted for further investigation. It is clear that there was enjoyment, but also difficulty in playing the game at times. Challenge is important to keep engagement in the game but difficulty needs to be tailored to achieve the right level of challenge in order not to reduce engagement through frustration (Csikszentmihalyi, 1990). Immersion is also important, and this was enhanced by the presence of competition in experiment 1. Therefore enjoyment, difficulty, challenge, immersion and also general enthusiasm needed to be investigated further to determine what within the game provides those elements and how important they are to the players' experiences with the game play. These elements were also reported in chapter 2 as being important features for designing games that make engaging educational tools. In addition to these elements, experiments 1 and 2 have shown that the effect of collaboration among friends and gender differences may also be important and need looking at further.

Experiment 3 therefore aimed to investigate the elements of enjoyment, difficulty, challenge, immersion and enthusiasm, but also friendship and gender further and to gather requirements for the maths learning game used in the final study of this PhD in fulfilment of objective 3 from Section 1.3. Experiment 3 is described in section 5.4 below.

5.4 Experiment 3

The aim of the questionnaire was to capture the opinions of the children from their experience of playing Harry Potter Lego and to draw out game design requirements for the final study of this PhD as determined by Objective 3 from section 1.2 in the Introduction. The questionnaire was focused on gathering qualitative data to assess students' motivation during the game-play. The questionnaire was also designed to get further requirements for the mathematics problem solving collaborative game described in the next chapter.

5.4.1 Questionnaire Design

The questionnaire included eight closed questions, where the children need to select an answer of either "yes", "Don't know" or "No". The majority of these questions gave them an opportunity to expand on their answer by asking "Why?" or asking them to give an example. The questionnaire aimed to investigate aspects of enjoyment, difficulty, challenge, immersion, enthusiasm, friendship and gender difference. The first four of these were aspects that were investigated in experiments 1 and 2 and are considered to give important indications of levels of collaboration and motivation to play the game. Friendship and gender difference were also selected here as it became apparent during experiments 1 and 2 that these may also have an impact on collaboration and motivation. The questionnaire can be seen in Appendix 5. The questions are also shown in Table 5.3, along with the element that each question aimed to investigate.

Questions	Element	Theme
Did you have fun playing the game? Why?	Enjoyment	M,EG
Was the game complex? Give an example.	Difficulty	M
Was the game challenging? Give an example.	Challenge	M,EM
Did you feel that time passed quickly?	Immersion	M,EG
Would you like to have more time playing the game? Why?		
Do you find the game exciting? Why?	Enthusiasm	M
Do you prefer to play with your friends? Why?	Friendship	EO
Do you prefer to play with children of the same gender? Why?	Gender	EO

Table 5-3: Questionnaire design

5.4.2 Participants

The study was conducted on fifteen groups with fourteen boys and sixteen girls. Four groups were of mixed gender; five groups consisted of only boys and six groups of only girls. The experiment was done at a local primary school (School A _ is the same School that stated in Chapter 4) during the school day at lunch time. Each group played Harry Potter Lego for 25 minutes. The questionnaire was distributed to the students after the game play sessions, and the researcher helped them by reading and explaining each question. Students were aged between eight and ten years old.

5.4.3 Results

Table 5.4 below shows the results of the questionnaire, normalised to represent the split in gender, and represented as percentages. Additional comments provided in answer to the questions can be found in Appendix 5 with certain comments highlighted in Tables 5.5-5.11.

Questions	**Answers (%) & Gender**					
	Yes		Not Really		No	
	B	G	B	G	B	G
Did you have fun playing the game?	43	53	3	0	0	0
Was the game complex?	0	6	21	23	26	23
Was the game challenging?	3	13	31	33	13	6
Did you feel that time passed quickly?	41	47	6	0	0	6
Would you like to have more time playing the game?	47	53	0	0	0	0
Did you find the game exciting?	33	53	13	0	0	0
Do you prefer to play with your friends?	43	47	0	3	3	3
Do you prefer to play with children of the same gender?	27	27	16	11	3	16

Table 5-4: Questionnaires Results

The data in Table 5.4 are further illustrated in the two bar charts shown below (Figures 5.1 and 5.2), for boys and girls respectively.

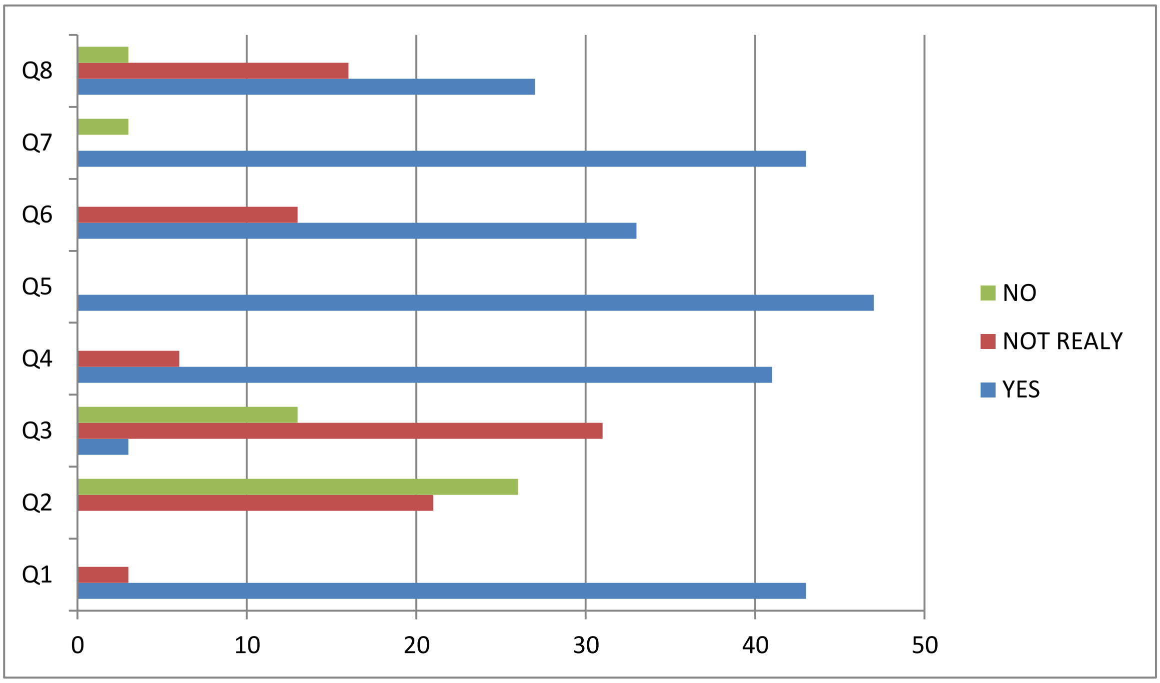


Figure 5-1: Questionnaires Boys Results

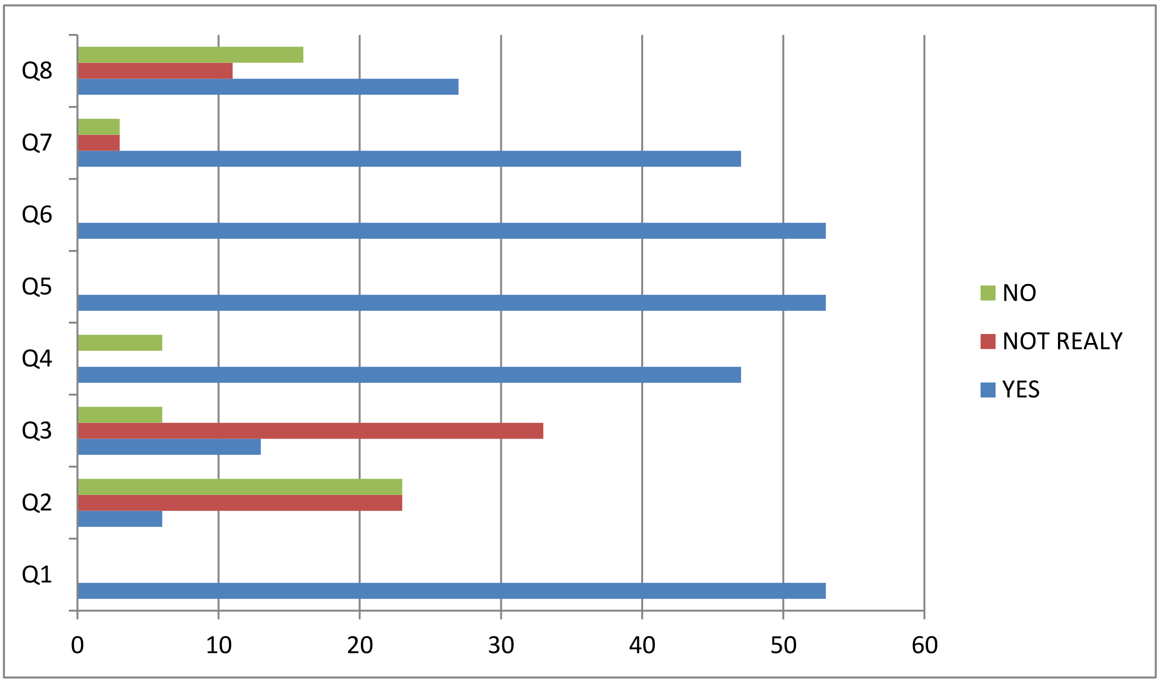


Figure 5-2: Questionnaires Girls Results

5.4.4 Analysis and Discussion

The questionnaire results are discussed in this section. The section is divided into the 7 elements that were focussed on in the questionnaire (as shown in Table 5.4 and Figures 5.1 and 5.2) and the results are discussed accordingly.

5.4.4.1 Enjoyment

As far as enjoyment is concerned, it can be seen that both genders (sixteen girls and thirteen boys) had strong positive opinions that Harry Potter Lego was an enjoyable game. The participants gave several reasons for their strong views which referred to their enjoyment of the Harry Potter character and the adventure within the game. Players also enjoyed working together (see Table 5.5).

Enjoyment		
Question	**Qualitative Answers**	**User requirements**
Did you have fun playing the game? Why?	"It has got lots of adventure like rebuilding things using magic." "It's a really exciting game." "Working as a team is really nice." "Because it is more fun to play the game as Harry than watch the movie" "Because you will have a chance to explore all around Harry Potter (I love Harry). It's really more fun to play the game than watch movie." "Because you can use different tools like water and fire" "Because it has different characters and fun levels."	• Adventure game • Collaboration • Simulate reality • Role playing

Table 5-5: Enjoyment

5.4.4.2 Difficulty

In light of this study, difficulty refers to players' abilities to understand and dominate the game system and mechanics such as being able to reach objectives and understand rules. It also refers to players' abilities to manipulate objects and interact with the environment and its objects (see Table 5.6). Two girls found the game difficult whereas none of the boys said that the game was difficult for them.

It was observed that the girls who experienced difficulties lacked experience and found the X-box controller confusing to use. Some of the children offered explanations as to why the game was not really complex for them and the main reasons indicated were that it was hard for some players to know what to do or how to achieve their goals within the game. Both boys and girls agreed that the instructions did help them a lot when playing the game, however, some of the girls stated that they thought that playing the game with boys would help them.

Difficulty		
Question	**Qualitative Answers**	**User requirements**
Was the game complex? Give an example.	"I feel like I am lost because I forget each time which button I need to press". "When you are using magic to build things it seems to be hard a little bit". "Just in the beginning of the game it's hard until you know what you need to do exactly". "The hardest thing is that you do not know what you need to do next". "The instructions help a lot". "If you are playing with boys they will help you a lot to play".	• Clear goals. • Clear and easy to use mechanisms for achieving goals.

Table 5-6: Difficulty

5.4.4.3 Challenge

As far as challenge is concerned, only a few children (four girls and one boy) considered Harry Potter Lego as a challenging game (see Table 5.7). A larger number of children (nine boys and ten girls) were ambivalent about whether they found the game challenging. They referred to their collaboration with the other player as helping them to overcome any challenge. Girls found some of the activities such as fighting ghosts very challenging while some of the boys did not consider this as challenging and they commented that there was nothing challenging in the game. The questionnaire results show that four boys and two girls did not feel any challenge when playing the game. They stated that this is because they found the game too simple. Lack of challenge within a game can contribute to a decrease in motivation during gameplay.

Paras and Bizzocchi (2005) confirmed that balanced challenge within the game contributes to an increase in children's motivation during game play. In other words, the game should not be so easy as to become boring for the children or too difficult which can lead children to be disappointed because they feel that success is unattainable.

Challenge		
Question	**Qualitative Answers**	**User requirements**
Was the game challenging? Give an example.	"Because it is a little bit confusing". "Because it's easy so we do not have enough challenge". "The challenge will be just when you are fighting the ghost". "Because we think it is too easy". "Because when we work together there is no challenge". "There is nothing in Harry Potter related to challenge, while racing you need to focus more".	• Different levels of challenge suitable for different abilities. • Use of action sequences to make the game challenging.

Table 5-7: Challenge

5.4.4.4 Immersion

Immersion can be described as a deep involvement in an activity to the extent that the subject does not keep track of time whereas enthusiasm can be thought of as energetic interest in a particular activity and an eagerness to be involved in it. Enthusiasm is discussed in more detail in the next section. With regards to immersion, the majority of children (twelve boys and fourteen girls) felt that the time passed quickly because they were engaging with playing the game, and they needed more time in order to complete the game level, although two girls did not want any extra time. Immersion is directly related to the extent to which children are involved in the game world. It is affected by the interaction within the game and the correct use of the game objectives and rules in order to obtain the best opportunity to control the actions in the game within the time given. Many of the players showed evidence that they did find the game immersive as is shown in Table 5.8.

Immersion		
Question	**Qualitative Answers**	**User requirements**
Did you feel that time passed quickly? Would you like to have more time playing the game? Why?	"Because it's really fun and more time will be helpful in order to complete the level". "Because you will know how to play more". "In order to discover things more". "Because I need to understand more how to play". "Because you will get used to the game more". "Because you do not need to do work".	• Provide opportunities for discovery. • Provide opportunity to reach goals. • Provide escapism from school environment and work.

Table 5-8: Immersion

5.4.4.5 Enthusiasm

Enthusiasm affects the extent to which the players interact with a game and how excited they become with the game process. There were just two boys who did not really find the game exciting because they prefer watching movies than playing games. However, the majority of the children (sixteen girls and ten boys) found Harry Potter Lego an exciting game to play. The children mentioned lots of elements within the game which contributed to their levels of enthusiasm. They particularly commented on elements of surprise and magic, but also appreciated the fact that objects were used that they could relate to from real life (see Table 5.9).

Enthusiasm		
Question	**Qualitative Answers**	**User requirements**
Did you find the game exciting? Why?	"Harry is going around and it's a lot of fun using different things like boats". "Because you get to use a lot of tools which are fun". "Because of the magic and it's a nice treat". "Definitely it is an exciting game because you do not know what will happen and we are surprised all the time". "Because it has lots of characters and tools like the horse and car".	• Variety. • Mystery. • Realistic objects. • Magic. • Suspense.

Table 5-9: Enthusiasm

5.4.4.6 Friendship (collaboration)

Friendship promotes the social aspect of collaboration and this social interaction can help participants to gain many collaborative skills. Children often like to work in groups especially if there are friendship relationships between them and the presence of such friendships allows their collaboration to be much better and for them to help and support each other. This study highlighted that friendship is important and directly contributes to increased interaction between the children, leading to increased motivation to play and reach the desired goals (see Table 5.10).

The majority of children (fourteen girls and thirteen boys) commented that they strongly favoured playing with friends and the ability to rely on the other player and share knowledge and discuss the game was important. However, one boy commented that he preferred to play on his own because he did not like the split screen, which was a feature of the game, during the collaboration. There were also two girls who did not like playing with friends because they preferred to be more independent when playing the game.

Friendship (Collaboration)		
Question	**Qualitative Answers**	**User requirements**
Do you prefer to play with your friends? Why?	"Because playing with friends will involve lots of fun and laughs". "Because if you play on your own it will be a hard game". "Because friends will not leave you behind but they will ask you if you need any help". "Because playing with a friend who knows how to play will help you to get to further levels". "Because we will work as a team and the computer will not be your friend".	• Ability to share knowledge • Supportive of team work • Ability to discuss the game with others

Table 5-10: Friendship through collaboration

5.4.4.7 Gender (collaboration)

An equal number of boys and girls (eight) preferred to play with the same gender. However, five boys and three girls were unsure as they were more interested in playing with another child if that child knew how to play the game, and in these circumstances, that knowledge was more important than their gender (see Table 5.11). In comparison with experiments 1 and 2, this study observed that girls showed a great deal of enthusiasm in playing Harry Potter Lego. There was a marked difference between their high levels of enthusiasm in this experiment and in experiments 1 and 2 where it was hard to persuade girls to take part. This may have been due to girls in the previous experiments feeling self-conscious as the environment dictated that boys would be nearby and potentially watching them.

There are certain previous studies into school children which showed that computer games were more effective with boys than with girls (De Jean et al., 1999; Young and Upitis, 1999). In contrast, the outcomes of a recent study into school children, by Ke and Grabowski (2007) found that gender did not influence the learning effectiveness and motivational appeal of games. Furthermore, a study of Papastergiou (2009) confirmed that digital game based learning can be equally effective and motivational for boys and girls.

In this experiment, five girls preferred not to play with the same gender and only one boy had no preference to play with either gender. Many studies (Cassell and Jenkins, 1998; Downes, 1999; Harris, 1999; Mumtaz, 2001; Facer, 2003) on domestic computer use and gender difference have shown that boys are more experienced with console game playing and they tend to be intensive game players because they play more frequently than girls. Consequently, boys become more confident and more able with hardware and software as their skills develop to a greater extent than girls (Cassell and

Jenkins, 1998; Downes, 1999; Papastergiou, 2008). It was also observed that the boys were happier playing with a small group of children around them collaborating and communicating with them and helping them in the game. Children around the groups were observed to show lots of interaction, communication and collaboration with the players.

Gender			
Question	**Qualitative Answers**		**User requirements**
Do you prefer to play with children of the same gender? Why?	**Girls** "Because girls like playing games and they are good at playing games". "Because it will be more comfortable". "Because sometimes boys can shout at you". "Because it's all about the game not the gender" "Because boys know better in computer game stuff, so I like to play with boys". "Because boys will help you more than girls".	**Boys** "Because girls cannot do things exactly the same". "Because girls don't really know how to deal with magic stuff like boys". "Because playing with boys will be funnier". "Girls sometimes know better than boys". "I prefer playing with both if he or she will know how to play".	• Appeal for both genders and for game play between mixed genders

Table 5-11: Gender (collaboration).

5.4.5 Summary

In experiment 3 children of both genders enjoyed playing Harry Potter Lego and found the type of game-play it offered and its collaborative features fun and engaging. Moreover, children mentioned that there were many features within the game which enhanced their enthusiasm such as the variety of mystery, realistic objects, magic and suspense. These features could enhance motivation in children to reach their goals.

However, the challenge among children was lost when playing Harry Potter Lego and children referred to the collaboration among them as decreasing their level of challenge because they felt more able to do things when working as teams. Whilst this cooperative working is valuable, the level of game difficulty is an important factor which can increase or decrease the challenge among children either because the game is too easy or too difficult for them, and this needs to be allowed for in the proposed game design. Buchanan (2007) indicated that games that are designed to respond to the players will elevate the level of the player's attraction within the first few minutes. Thus, the players' motivation will increase, encouraging the players to continue learning the game. Prensky (2002) illustrated that a good game design can keep student interest and capture their attention so that they are engaged all the time, while in the classroom this is not always the primary goal for the teachers. However, these are the important goals that should be taken into account when designing a video game. It can clearly be seen that the games which provide different levels of difficulty for players of different abilities and more complex challenges can enhance and improve children's motivation and interaction.

In summary, experiment 3 has addressed research question three from section 1.1 of the Introduction. This has led to the following key features of the proposed game:

- Playful environment.
- Characteristics incorporating challenge, curiosity, control, enthusiasm, collaboration, complexity, fantasy.
- Be well structured to provide clear goals, and rules.
- Be gender neutral.
- Clear storyline.

5.5 Conclusion

Three experiments were conducted as part of study two, the purpose of which was to identify whether and how children collaborate in a problem solving computer game and what motivates them to play that game, as well as identifying requirements for a mathematics problem solving game.

Despite research suggesting that involving competition can lead to the learning-based game being more enjoyable, no positive influence was seen from the competition-based experiment on children's enjoyment (for example, codes for enthusiasm and fun occurred with similar frequencies in both states) when playing the game, but there were some indications that competition might have increased engagement with the game mechanic and possibly also motivation to play the game.

The contribution of this chapter has been to provide the requirements for the maths problem solving collaborative learning game, as gathered from the two reported studies, and the next chapter moves on to the design and implementation of the game (objective 4, section 1.2, Chapter 1). Later in chapter 7, study three will illustrate the final experiment which investigates the role of collaboration in engagement with the game mechanic and thus in engagement with the learning outcomes of the game designed.

6 Game Design

6.1 Introduction

The overall set of requirements for a collaborative computer game to teach maths problem solving design was gathered through chapters 2, 4 and 5. These are combined and summarised in Table 6.1 below.

Source	Requirement
Literature review, Chapter 2	• An environment that supports learning of maths problem solving • Engaging • Serious game • Collaborative • Incorporating fantasy, challenge, complexity, control, clear rules, goals and feedback
Observations, Chapter 4	• Environment needs to encapsulate fun, stories and games. • Scaffolding and rewards/incentives • Kinaesthetic learning • Use of technology
Questionnaires, Chapter 4	• Games, collaboration, ability to share and discuss maths problems
Chapter 5	• Playful environment • Characteristics incorporating challenge, curiosity, control, enthusiasm, collaboration, complexity, fantasy • Be well structured to provide clear goals, and rules • Be gender neutral • Clear storyline

Table 6-1: Game Design Requirements

This chapter outlines the requirements in more detail and tests the initial collaborative computer game design (as stated in Objective 4 Section 1.2) in a real physical learning environment as part of the User Centred Design approach. The complete design of the collaborative computer game that is used in the main study of this PhD is also described here along with the consequent adaptations made. The game evaluation is described in the next chapter which details the final study of this PhD and attempts to answer research questions one, two, three and four.

6.2 Learning outcomes of the game

The design of this game was conducted in collaboration with a UK Primary School year 3 (corresponding to children aged 7-8 years) teacher (School A). The main requirement given by the teacher was to be able to present arithmetic problems through different activities. It was jointly decided that mathematics problem solving exercises combining several mathematical operations would be suitable to incorporate in the design of the game. These target specific sections of the National Curriculum, as shown in Table 6.2 below which states the corresponding learning outcomes to be encoded in the game.

Section	Learning Outcome
Key Skills	Communication, Application of Number, IT, Working with others, Improving on own learning performance, Problem solving
Ma-KS2 1- **Problem Solving**	**Using and applying number and operations** Find different ways of approaching a problem in order to overcome any difficulties Make mental estimates of the answers to calculations; check results **Communicating** Communicate mathematically, including the use of precise mathematical language **Reasoning** Search for pattern in their results; develop logical thinking and explain their reasoning choose and use an appropriate way to calculate and explain their methods and reasoning
Ma2-KS2 2- **Numbers and the number system**	**Counting** Count on and back in tens or hundreds from any two- or three-digit number; recognise and continue number sequences formed by counting on or back in steps of constant size from any integer, extending to negative integers when counting back **Mental methods** Recall all addition and subtraction facts for each number to 20 Work out what they need to add to any two-digit number to make 100, then add or subtract any pair of two-digit whole numbers; handle particular cases of three-digit and four-digit additions and subtractions by using compensation or other methods Recall multiplication facts

Table 6-2: Learning Outcomes Taken from the UK National Curriculum (2013)[2]

[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335158/PRIMARY_national_curriculum_-Mathematics_220714.pdf

The idea for the game was that arithmetic problems would be applied through presenting sets of different numbers and mathematical operations in a way that would require a sequence of calculations and a number square to reach a target number. Figure 6.1 illustrates an example of such a number square which needs appropriate numbers to be added to the empty locations to enable a calculation of the horizontal and vertical rows to give the correct outcome.

	1		3
2		1	4
1		5	
		2	1

Figure 6-1: Number Square requiring pupils to fill in blanks
In this case each line adds up to 10

Specifically the aim of the number square game was to address the following requirements:

- Develop understanding of the four number operations and the relationships between them including inverses; using the related vocabulary; choosing suitable number operations to solve a given problem; recognising similar problems to which they apply and approaching problems flexibly, including trying alternative approaches to overcome any difficulties

- Identify the data necessary to solve a given problem
- Select and use appropriate calculation skills to solve problems
- Explain and justify their methods and reasoning.

The game was designed to present players with a problem solving situation where players were encouraged to collaborate in solving the problem by discussing strategies and their validity. The aim was therefore to enhance pupil willingness to engage with practice at the same time as encouraging pupils to verbalise and explain the problem solving process (Al-Washmi, et al. 2014).

6.3 Game Theme and Storyline

The game has been designed as an adventure/fantasy game, as identified in Chapter 5, where the style is similar in content to CBBC games (BBC, 2014) which have popularity among children of this age group. Requirements of the game theme include the incorporation of challenge, curiosity, control, enthusiasm, collaboration, support for both genders, complexity, fantasy and providing clear goals and well-structured rules in order to encourage the players to be highly engaged and motivated to play the game and to enjoy doing so. The game should be fun despite having educational objectives. Story lines should be provided within the game which will clearly guide learners to solve tasks in order to meet the learning objectives.

The story behind the game is focussed around a group of school children who are on a school field-trip to a forest. They are walking with their teachers into the forest, a dark and mysterious place, when they come across a magical zone. Suddenly, they realise that their teachers have become separated from them. While they are looking around for their teachers a witch appears. The witch reveals that their teachers have been kidnapped and gives the children one condition in order to release their teachers; she asks the children to collect a set of items (her cat, broomstick, cauldron etc.). Figure 6.2 shows the images from the game storyline sequence.

In the game, therefore, the children need to play in pairs to collect objects and to do this they need to choose correct numbers and solve different arithmetic problems in a collaborative, fun manner. The design of this collaborative mathematical computer game incorporates two different levels, the Spider Web and the Stepping Stones and these are described in Section 6.6.

Figure 6-2: Images from the game storyline

Several factors within this game are designed to immerse players and keep their attention and motivation to play. As well as the game theme and storyline, these include the game mechanic, characters and the game interface and are discussed in the next sections. Most importantly, section 6.4 critically examines how to effectively encode the learning outcomes into the game mechanic to ensure that engagement with the game mechanic also establishes engagement with the learning outcomes. This is key to designing an effective learning game (Habgood et al., 2005; Habgood, 2007; Habgood and Ainsworth, 2011).

Section 6.5 presents the characters designed for the game and the two game levels designed; the spider game level and the stepping stones level progression are then presented in section 6.6, before the pilot study of the game is discussed in section 6.7.

6.4 Game Mechanic

The game mechanic is a fundamental part of game play, the design of which needs to be carefully crafted, especially in learning games, to ensure the player engages in the correct activity for the game’s purpose (Villalta et al. 2011). The game mechanic is a way to summarize a game’s rules and, in educational games, it requires a strong and flexible connection between the interface and the instructional aspects of the game through actions and interaction. As the player plays the game the game contexts are manipulated in order to achieve the desired learning goals (Cobb, 2000).

However, many researchers argue the difficulty of incorporating learning outcomes into the game mechanic whilst keeping the game fun to play. In fact, many state that this is something yet to be effectively achieved (Squire 2003; Moreno-Ger et al. 2008; Villalta et al. 2011). Others argue that this is possible and in doing so correctly and with a well-designed game, the learning game can improve learning (Prensky 2001; Gee 2003; Gee 2004; Gee 2005; Shaffer 2005; Shaffer 2006). It is an aim of this study to examine this contention further to shed light upon the differences of opinion. This will be in line with verifying research question one from Section 1.1.

This game aims to merge the identified learning outcomes and the approaches observed in the classroom with the game mechanic by including different activities like repetition (practice), innovation (thinking of new ways to solve problems), and collaboration (sharing and discussing knowledge). This is intended to help students visualize certain concepts or events in relation to the topics that they will be learning and also integrate challenge into the game to promote flow (Csikszentmihalyi, 1990). In doing so this should enhance the player interaction and maintain their engagement.

This connection between the interface and the instructional aspects is present throughout the game's duration to foster attention, trust and satisfaction and to increase learners' motivation to achieve the instructional goals within the game. For example, the game guides interactivity through engagement with a sequence of actions within the game play and through collaboration between players. There is great educational potential in living the events of a story through the game in order to learn, since it leads participants to make decisions and understand complex phenomena through solving problems (Aldinger et al., 2005) as well as promoting a metacognitive awareness of the learning process through learning by doing and giving reasoning (Ke, 2008b). This game is designed to present an engaging storyline combined with a game mechanic which encodes the need to discuss and choose appropriate courses of action and perform arithmetic operations to progress through the game and reach the goal of collecting the witch's objects. The next section describes the design of the characters which are used by players in the storyline before moving on to the game design itself in section 6.6.

6.5 Game Characters

The characters have been designed in an age-appropriate way for children aged 7-10 years old. The designs were piloted with the target children and also approved by the class teacher at (School A) as being appropriate for children of this age group.

The children are presented with six named characters to choose from (See Figure 6.3).

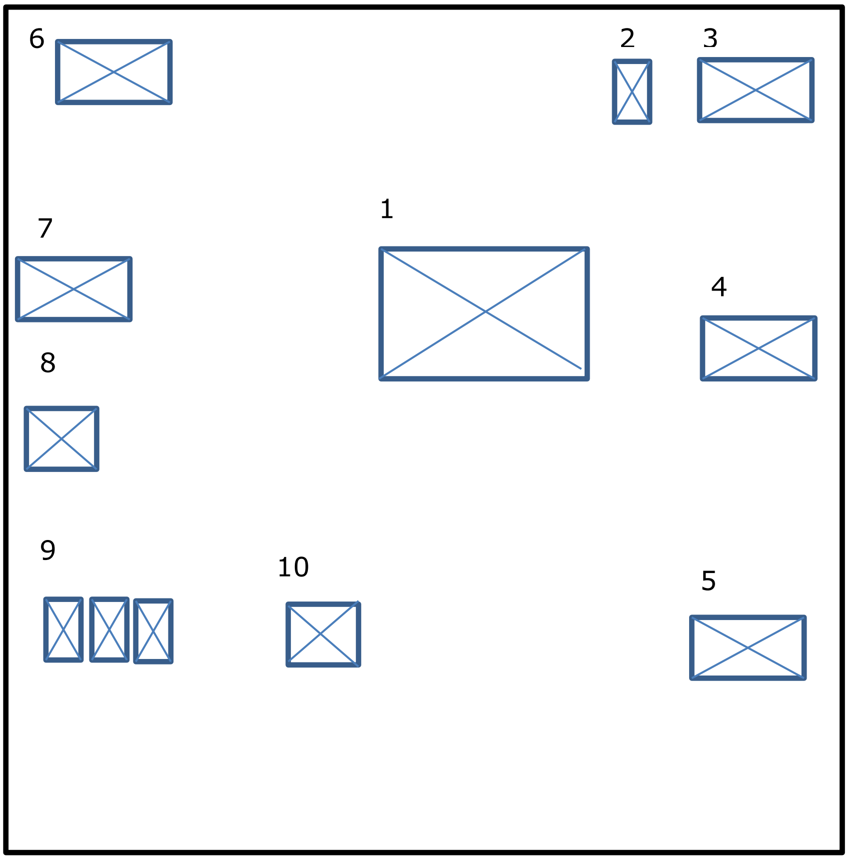
Figure 6-3: Game Characters

Both genders have been taken into consideration through the creation of characters of different genders and children are free to choose their own character. These characters are used throughout the game to represent the player. Choice of character can be made using either the mouse or keyboard arrows. The game system will not allow two players to select the same character.

6.6 Game Levels

6.6.1 Spider Web

The Spider Web game design aims to engage children with solving different mathematical tasks as part of their involvement in the storyline and progression towards the ultimate goal; that of returning their teacher. Figure 6.4 shows a wireframe of the interface and a screenshot of the game interface is shown in Figure 6.5. A spider web consists of 12 threads. Each thread carries three bugs which have different values associated. The aim is for the players to select two bugs at a time so that, when combined with the mathematical operator provided by the system, they produce a result that is added to a running total. This running total moves towards a value that is the final goal of the game. Figure 6.6 is a flow chart showing progression through the Spider Web game.



1 Spider web
2 Mathematical operator to be used for current turn
3 Calculation box showing current sum of values on collected bugs for current turn
4 Running total of all calculation values
5 Number goal to be reached
6 Player name
7 Witch's items already collected
8 Visual timer
9 Witch's items to be collected
10 List of witch's items that can be purchased with points (Pop up dialog box).

Figure 6-4: Spider Web Game Wireframe

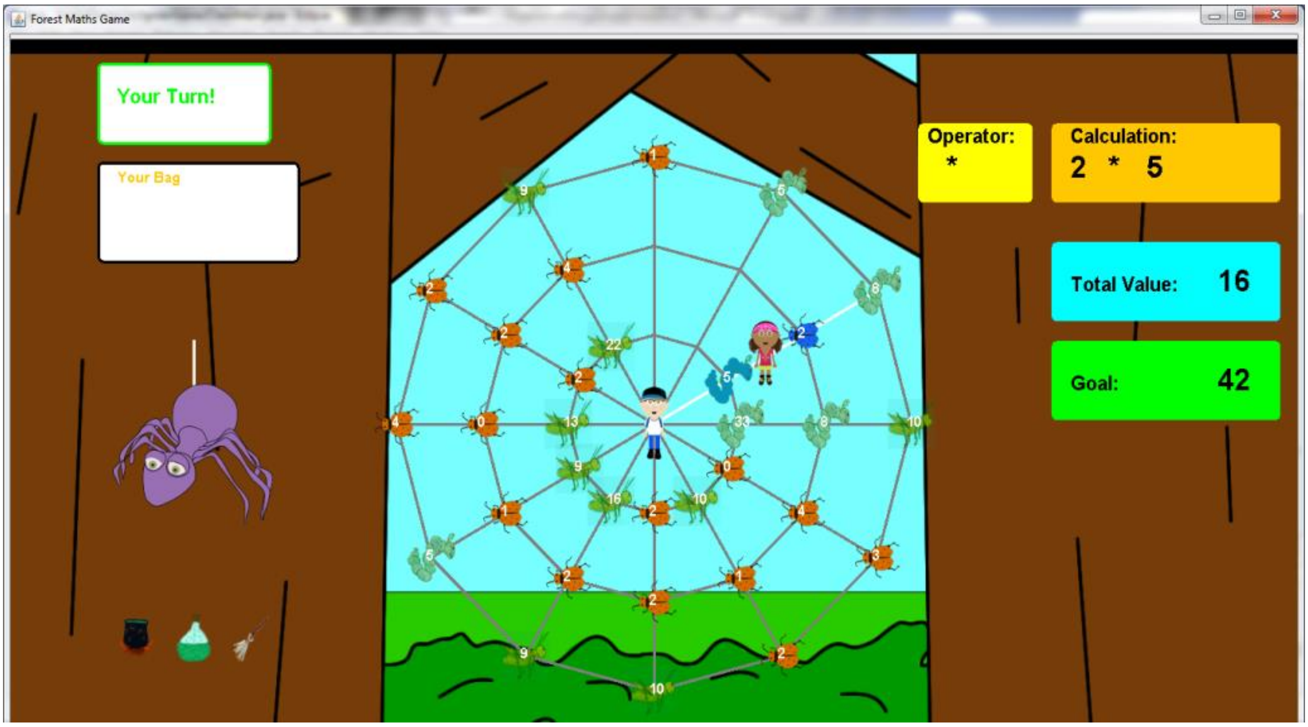


Figure 6-5: Spider Web Game Screenshot

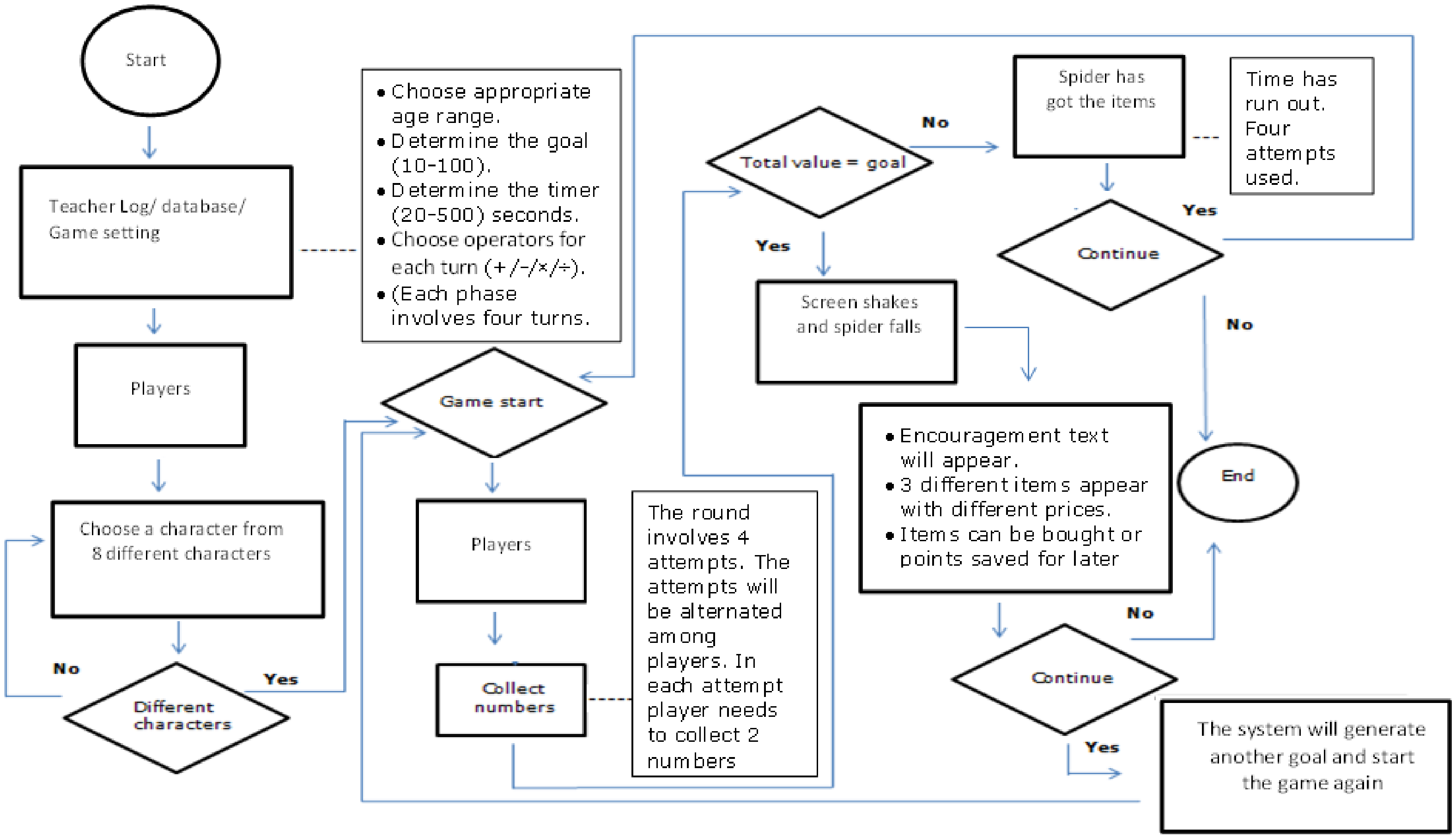
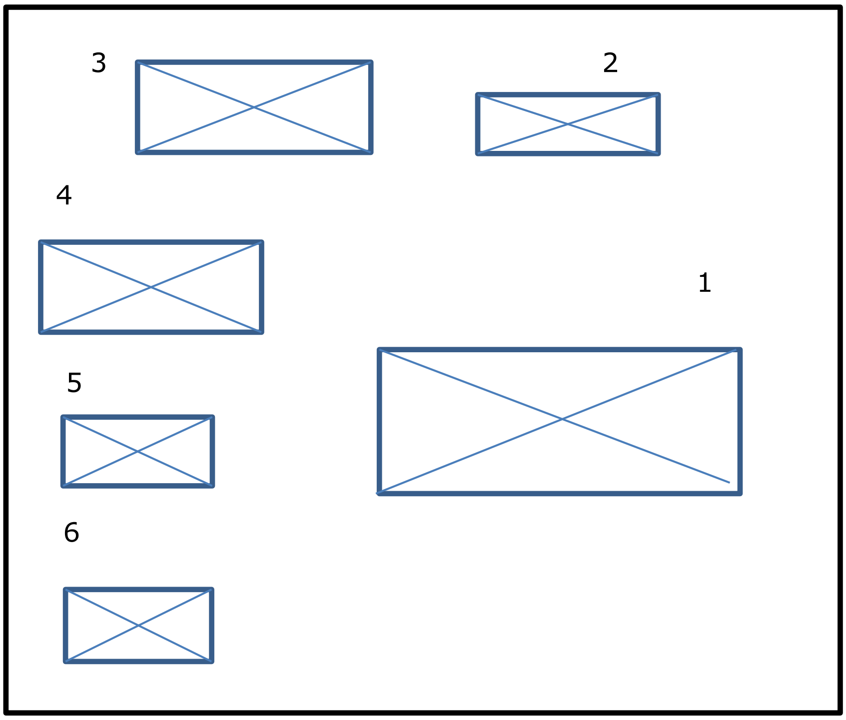


Figure 6-6: Spider Web flow charts

6.6.2 Stepping Stones

The game is designed to be played by two players. This level has been designed around a mathematics "number square" (see figure 6.1) with some alterations. The design consists of a lake with solid stepping stones (containing numbers) and transparent stepping stones (value to be calculated). Already placed numbers are either black (a support value to be used in a calculation) or orange (the result of a calculation.) The aim is for the player to take a mathematical operator, floating on the lake and use the numbers to calculate the result. Each player is assigned either an odd or even number by turning the handle on a "mystical number machine" which they can accept or reject. Initially the design intended that players would have different tasks to do within the game as in the Harry Potter Lego game (e.g. one turns the handle, the other selects the number to be placed in the stepping stones grid) and it was intended that they therefore needed to collaborate and discuss this with each other. However, both players ended up sharing the same screen (because the game was not completely built) where each player turned the handle and selected the number before passing on to the other player and lots of collaboration still took place. Figure 6.7 below shows a wireframe diagram of the Stepping Stone game. Figure 6.8

shows a screenshot of the level. Figure 6.9 illustrates the game level progression through a flow chart.



1 Lake with stepping stones number square

2 "Mystical number machine" to produce numbers

3 Switch button to switch between even or odd number production

4 Reset button resets the level

5 Store of witch's items already collected

6 Witch's items required to complete the level

Figure 6-7: Stepping Stones Game Wireframe

Figure 6-8: Stepping Stones Game Screenshot

The next section presents the implementation of the game software and then section 6.8 moves on to describe the pilot testing of the software.

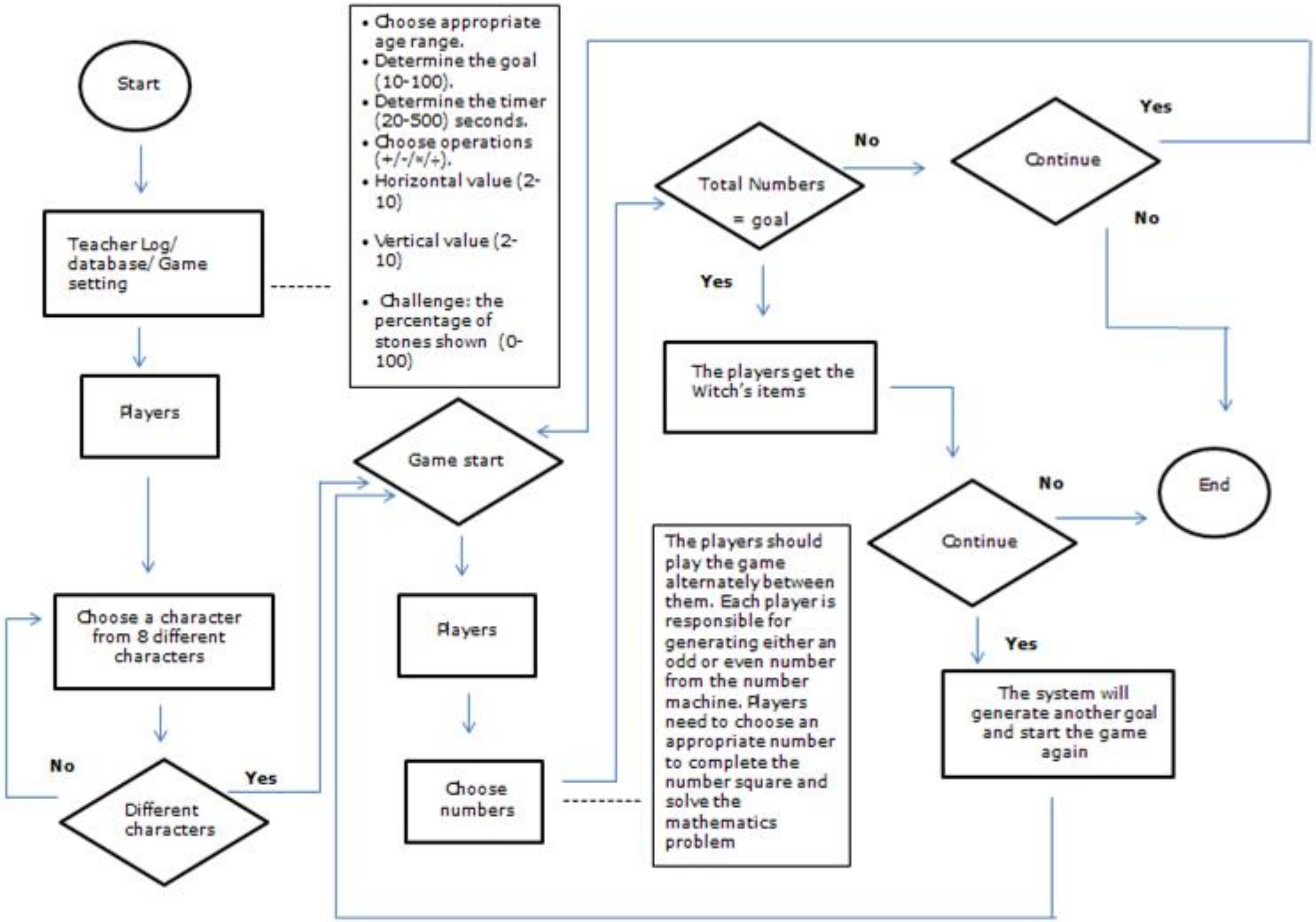


Figure 6-9: Stepping Stone flow charts

6.7 Software Implementation

The game was implemented with a client server architecture set up over a Local Area Network. The network was controlled by the server and the client was connected through a TCP/IP connection. The server was contained in a Java Package which is shown as the Network Package in Figure 6.10 below and the game components were set up as the client. The server and client did not need to run on different machines and thus the configuration in the experiments was designed to have a server running on a laptop that was transported to the schools in which the tests took place. A number of other laptops were provided which ran only the client. The network connection was made over a wireless router. At the start of any session the server software was first run and settings entered. Each component of the package and each sub-component used a Model View Controller (MVC) approach. The view for any component was written in FXML using a graphic interface. Utility classes were also included which dealt with loading configuration files for each component. These are shown as the Settings package in Figure 6.10 which also provides utilities used by the other components such as for setting the difficulty level, saving game scores and saving data from the click streams. Thus the teacher interface consisted of an FXML view form with a controller class and model to collect the settings that were used in the game. The teacher interface launched from the main controller once the network configuration was set. The teacher interface then provided options for the teacher to set the difficulty level, such as the variety of operators and difficulty of the calculation. This was then saved in a settings file which was available to the clients during game running. The clients were then launched on each computer. The client again worked on an MVC basis with sub-components for spider controller and player controller. The software was written in Java using Eclipse as the IDE. Test driven development was used on the models using JUnit. All software was stored on a private GitHub repository. Changes to the software were mapped using issue handling in GitHub. No software changes were committed to the final build until all regression tests had passed.

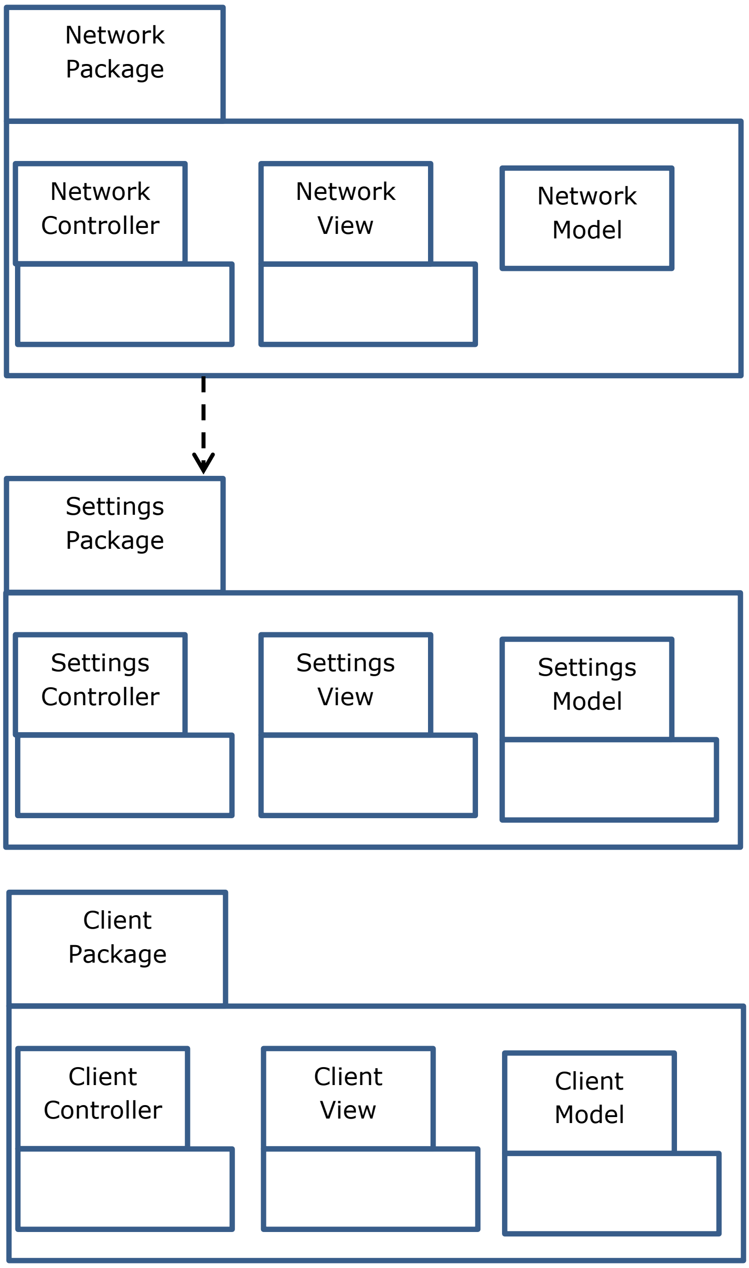


Figure 6-10: UML diagram showing the packages of the game

The Network (Server) package acts as the overall controller, and defines the settings. The Client provides the game and connects to the Network and then loads the settings from the Settings model

6.8 Pilot study (Usability Testing)

A pilot study was conducted to test the game in terms of usability and its potential for promoting engagement and collaboration. The pilot study took place in the classrooms at a local primary school (School C). The study took the whole of the school day and involved short sessions of around 20 minutes' duration.

Each session involved approximately 30 children and these were divided into seven groups from Reception (4 years old) through to Year 6 (aged 11). The children worked as teams where two individuals had to play the game each with their own computer, for the Spider Web level. For the Stepping Stones level each pair shared a computer because the level had not been programmed at the time to be multi-player. At the beginning of each session the researcher explained the game's rules and gave instructions to the children on how to play the game.

During the sessions it transpired that the challenge level of the game needed to be set to be appropriate for children with different abilities. This was done at the time by re-programming the difficulty levels of the game and this is discussed again later in section 6.8.2 which describes the resulting Teacher Control Interface that was subsequently added. Observations were made of the game play and hand-written notes taken. The next section will discuss the observations in more detail.

6.8.1 Observations

At the beginning, the children were able to select characters successfully without any difficulty. The children liked both the storyline and characters of the game very much and enjoyed choosing their game character. A lot of collaboration was observed both within each pair playing and between the pairs. However, there was a lot of variability in attainment level for each age group as described below.

Younger children (aged 5-7 years) showed lots of attraction to the game storyline and characters. The children were interested in the mathematics concepts even though they found it challenging. Challenge presented itself through the diversity of mathematical operators used in the calculations that needed to be performed. However, those children who struggled looked for help easily from an adult or a more knowledgeable pair of players. Some children found it harder to adapt to the need for collaboration than others.

Children aged 8-10 years old were observed to struggle with the time given to complete the mathematics tasks. They appeared to find it hard to think how to solve the problem within the time allowed. For example, children were only able to go through some of the threads in the spider game before the timer had elapsed and they found this quite frustrating. This indicated the need for the game system to be more flexible in terms of use.

When observing the oldest children (aged 10-11) the distinction between gender behaviours was obvious. The girls were interested in the idea of sharing effort through collaborating to complete the tasks. The boys, on the other hand, initially appeared to be completely disinterested in the game tasks because they assumed it was too easy. However the boys were encouraged to play the game and then they started to enjoy the collaborative game play. In particular, once the boys were engaged with the game play they showed lots of motivation to play and reach the goal using discussion and information sharing. This indicated that it would be beneficial for this age range to have tasks which are more challenging for them.

During the sessions there were some children who had special needs and they were observed to enjoy and engage with the game. In particular there were some deaf children who were observed to engage fully with the game and collaborated using sign language either between each other or even with children who could hear but who were able to use sign language because they were shared the same school.

Overall the teachers at School C were impressed with the game concepts and the collaborative approach for playing the game. They gave feedback which emphasised the value of learning collaboratively using the game.

6.8.2 Discussion

The pilot study demonstrated that collaboration played a significant role in helping the children progress through the game. It also appeared to enhance their motivation to solve the mathematical problems through engaging with the game mechanic.

However, from the observations it was found that the game settings needed to be more flexible in two ways. The main request was for the game challenge to be adjustable by having the ability to change the game difficulty level. Secondly, the period of the timer needed to be adaptable for those who needed longer to solve the problems.

As a result of this the game interface was adapted to incorporate a game settings panel (see figure 6.11) in order to allow a teacher to easily adjust settings at the beginning of each session to suit different ages and abilities. In doing this the player attainment level can be tailored and appropriate learning outcomes set by the teacher.

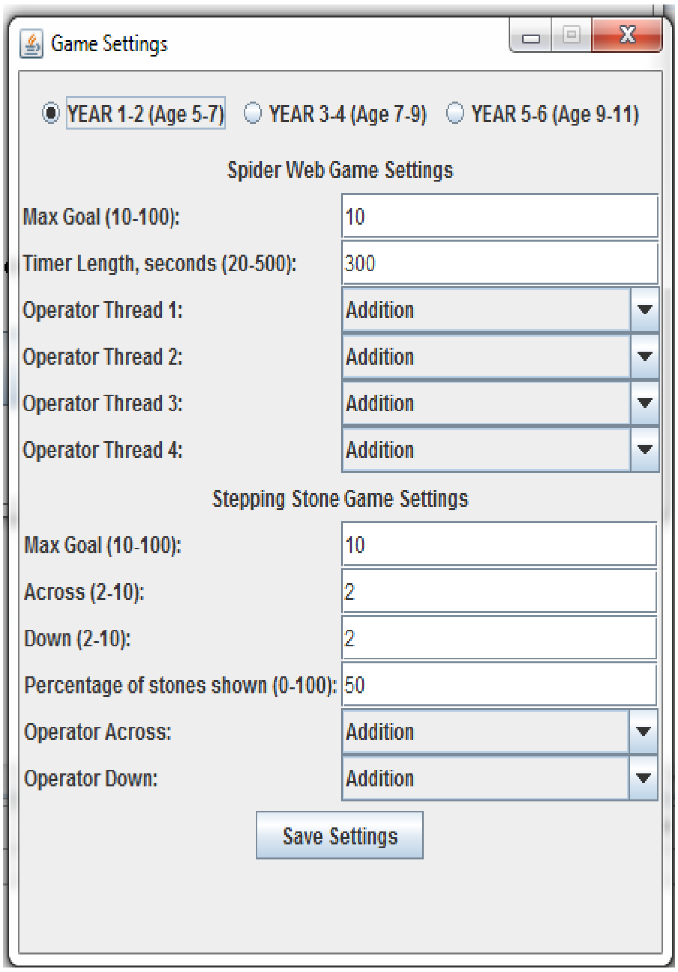


Figure 6-11: Teacher Control Interface

In the teacher control interface shown in Figure 6.11 the following changes can be made by the teacher:

- The teachers can control the game time to be longer or shorter in order to make it more or less challenging.
- They can adapt difficulty through restricting or increasing the numbers and types of maths operators to

be used to solve the mathematics problems in both levels.

- They can increase or decrease the target goal value of the game that needs to be reached.
- They can adjust the timer.
- The stepping stones "magic square" problem can be adjusted to have more or fewer columns and rows.

In this way the maths tasks could be facilitated more within the game play for early stage learners by using addition only whereas multiplication and division can be added to the maths problems for those who need the tasks to be more challenging.

6.9 Conclusion

Perfect video games design should involve different levels of practice from the simple such as learning the required button combinations through to assessing problems and developing and testing various solutions (Dickey, 2006). The observations in the pilot study indicated that children of different ages found the collaborative maths problem solving game engaging but that some tailoring of the interface was required to adapt the level of challenge. As mentioned in Chapter 5 it is important to regulate the level of challenge in order to maintain a state of flow through the game. Due to this an additional element of the interface was developed to enable the teachers to adapt challenge according to ability, age and learning outcomes.

Educational games that combine collaborative work and technology can be one of the most valuable educational tools for teachers in the classroom (Alvarez, 2006). The pilot study clearly showed that children of all ages collaborated; the children shared the experience of playing the game both within and between pairs and were observed to discuss how to solve the problems and reach their goals. Now that the interface is more adaptable it can more readily support a diversity of players' skills and can allow the game to be adjusted in terms of instructional complexity. Therefore, it is hoped that the game will give children the opportunity to build and encourage their confidence by enabling them to control and manipulate objects to solve the mathematical problems and share knowledge in a way that scaffolds each others' learning.

This chapter provides the contribution of a collaborative maths problem solving game which has been shown to engage pupils in the learning environment, encourage collaboration between pupils and one which is adaptable in the level of challenge it presents to pupils.

In this chapter Objective 4 (Section 1.2) has been met. Following the success of the pilot study the next stage was to evaluate the game in a larger experiment to examine its effectiveness and to enable research questions one, two, four and five in Section 1.1 to be answered. The next chapter therefore details the design of the experiment that forms the final study of this PhD and the findings that come from this (Objectives 5 and 6 in Section 1.2). The final chapter (chapter 8) then concludes the PhD work and proposes further work.

7 Final Study: Evaluation

7.1 Introduction

Chapters 2, 4 and 5 have identified several factors important for developing maths problem solving skills in children and for the design of a computer game that promotes the development of such skills. Factors identified include a strong need for collaboration to enable knowledge sharing and scaffolding, a good storyline with clear goals to encourage engagement and flow within the game and an appropriate level of challenge when playing the game. The chapters have also discussed the critical importance of effectively encoding the learning outcomes within the game mechanic. Chapter 6 presented the design of the game and the pilot study.

In this chapter the final study is presented which aims to evaluate the game against the research questions one, two, four and five that identified in Chapter 1. In doing so this chapter firstly describes the experimental design of the final study. In this experiment two groups of children have been used from a local school. The first group used the computer game in their school classroom and the second group acted as a control group and used a non-computer-based game (dice game) with the same learning outcomes.

The next sections therefore describe the design of the dice game experiment (see Section 7.2) which fulfils Objective 5 from Section 1.2 and then the design of the overall study involving both the dice game experiment and the computer game experiment (Section 7.3). Section 7.4 describes the data collection methods used and the data are then presented and analysed in section 7.5. Finally the study is discussed in section 7.6, thus fulfilling the Objective 6 and addressing the research questions outlined.

7.2 Collaborative Dice Game – Control Experiment

7.2.1 Game Design

Adding any new activity or teaching technique into the normal school process will naturally stimulate pupils to engage with the activity (Jensen, 2005). Thus the control study was designed to introduce a non-computer version of a collaborative maths problem solving game to minimise the effect of novelty of the computer game so that the computer game efficacy could be properly investigated.

The dice game control experiment was designed using a combination of existing games available at the time in the UK market. The main game used was MATH DICE[2] (see figure 7.1), and this was combined with two further dice, with mathematical operators on their faces, taken from another Math DICE game (see figure 7.2).

Figure 7-1: MATH DICE Game

(from: http://thinkfun.com/mathdicejr)

1-3 Sided Maths Operations Dice (addition – subtraction-Aaahhh)

1-4 Sided Maths Operations Dice (addition – subtraction- multiplication-Aaahhh)

Figure 7-2: Math Operation Dice

(from: http://thinkfun.com/mathdicejr)

The third element was a jigsaw puzzle, with one of three different puzzle boards used per group of children (see figure 7.3). The dice game was designed to be a substitute for the

[2] http://thinkfun.com/mathdicejr

computer game where participants had to solve maths problems and select pieces of a puzzle in order to complete an overall goal in a similar manner to the computer game. This kind of game was specifically chosen as it represents the type of games already played in the school classroom (see Chapter 4). The game was approved by the teacher as appropriate, and the teacher confirmed that that specific dice maths game had not been played before at school.

Figure 7-3: Puzzle Boards used in the dice game

In order to play the game players are required to put together mathematics equations in order to reach a target number. The aim of the two additional mathematics operator dice was to make the game challenge adaptable, as with the computer game. In the first level of the game the pupils start with a pink dice containing addition and subtraction operators on its faces. Once they complete this level, or should they need more challenge to start with, they can move to the next level which uses an orange dice with addition, subtraction and multiplication operators on its faces. Both dice also include an "Aaahhh" option on some faces and this allows players to double any of the numbers (only once per turn) on the other dice to solve the maths problem. The incorporation of the jigsaw puzzle aimed to increase engagement with the game and provide the goal of completing the puzzle. Players are required to work out how many different ways can be used to reach the target number using the available numbers and operator. The number of solutions found then determines the number of jigsaw pieces the players can choose to put into place in the jigsaw puzzle. The game rules are described in section 7.2.2 with images to illustrate.

7.2.2 Game Rules

The game lasts for 25 minutes. A pair of players are required to play the game and the players are encouraged to collaborate with each other to complete the level. To enhance each player’s engagement, they each choose a coloured counter and take turns to throw the dice and move their counter but they need to support each other in doing this.

Step 1 is to roll the 12-sided target dice. The number that appears will be the target goal to be achieved (see Figure 7.4).

Figure 7-4: Step 1 Dice Game

Step 2 is to roll the operator dice and the five 6-sided scoring dice together. Pupils will use the pink operator dice in the first couple of sessions (addition, subtraction and Aaahhh) and then the level of difficulty will be increased by using the orange operator dice (addition, subtraction, multiplication, Aaahhh) (see Figure 7.5).

Figure 7-5: Step 2 Dice Game

The pupils then need to work out different solutions using the operator and available numbers to reach the target goal **(step 3)**. If the dice lands with the "Aaahhh" face on top, the pupils will have the opportunity to double any of the scoring number dices, as a bonus, and they then also need to re-throw the operator dice to obtain an operator.

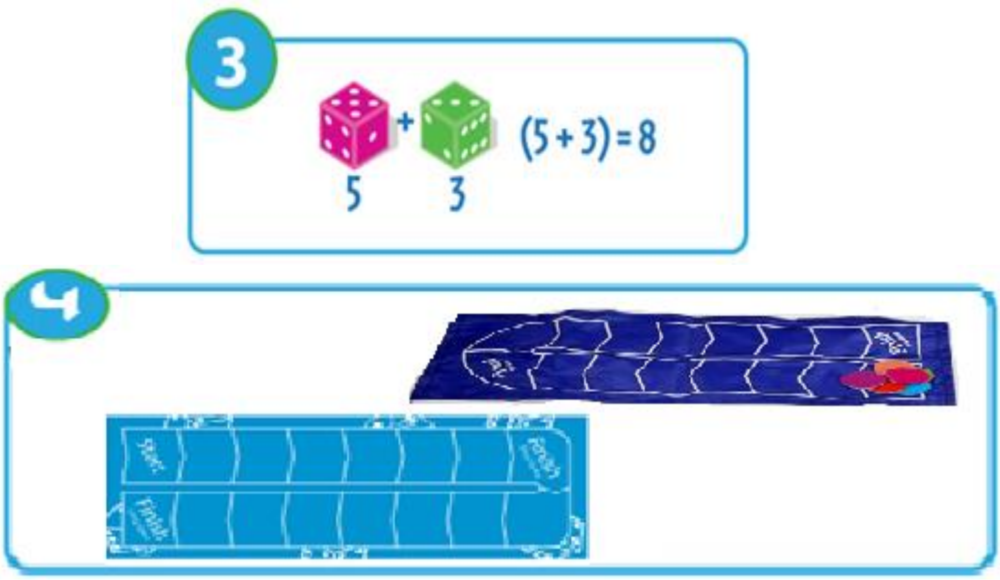


Figure 7-6: Step 3 & 4 Dice Game

With each turn, the pupils move their chosen counter along a grid, as shown in **step 4** above. The number of places they can move depends on the number of scoring dice (not including the operator dice) that they use to create solutions to the problem. The aim of this is to encourage them to look for as many options as possible (see Figure 7.6). They can move around the grid more than once within a game session. In addition to this, the number of solutions they find determines the number of jigsaw pieces they can choose to complete the puzzle during each turn. The game ends when the players have completed the jigsaw puzzle. Figure 7.7 below shows the Dice Game flow chart to illustrate the game process.

During game play the researcher was present and encouraged players to "think again" if it was apparent that there were further solutions available. It was possible to use more than two scoring dice i.e. use more than 2 numbers, to make a solution (e.g. 3+2+1 = 6). If scoring dice values were too big to enable the total to be reached then the researcher used one of 3 options to allow the players to progress: they could roll again; they could choose another operator or they could use 0 as part of the calculation.

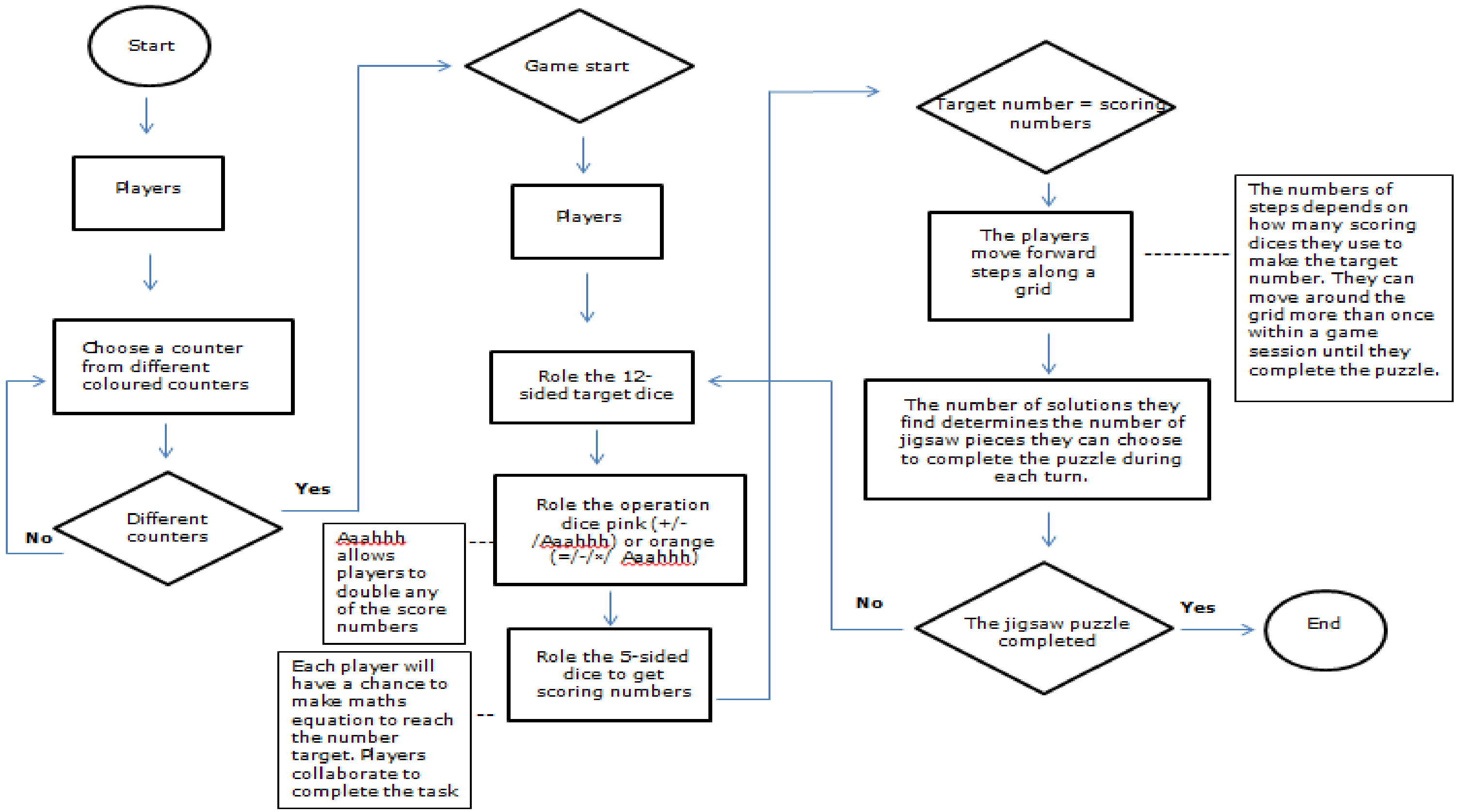


Figure 7-7: Dice Board Game flow charts

7.3 Study Design

The study was designed so that roughly equal numbers of participants would take part in the dice game (control group) as in the computer game. Pre- and post-test and questionnaires were designed and these were approved by the teacher. These intended to examine various aspects of the pupils' abilities and attitudes, and are described in detail in section 7.3.1 along with other data collection methods used (e.g. focus groups and interviews). The full study is described in Section 7.5 and the results of the study are shown in Section 7.6.

Prior to conducting the full experiment a pilot study was conducted to test that target participants would understand the goals of both the computer game and the dice game and also to test the appropriateness and clarity of the questionnaires and this is detailed in section 7.4.

7.3.1 Data Collection Methods

Several methods of data collection were used in the study including pre- and post-tests, observations, focus groups, interviews and click streams as outlined in Chapter 3. This section describes these methods in more detail.

7.3.1.1 Pre- and Post-Tests

A number of pre- and post-tests were designed in order to measure certain attitudes and abilities before and after the five weeks so that the effect of playing the game could be gauged. Firstly, each pupil was given a multiple choice test with 12 questions examining their ability in maths. The questions were designed to be of a similar style to those pupils were already familiar with from school and also to be of the types of maths problem solving the pupils would encounter when playing the games. They also varied in their difficulty level in order to test pupils of different abilities. The questions also followed the theme of the game storyline to keep consistency. From this test each pupil was awarded a score out of 40. Each of the questions in this test included an "I don't know" option and the aim of this was to gain an idea of confidence and motivation to answer each question. At the end of the 5 weeks the pupils again completed the test with the same questions but with different numbers used in each sum so that pupils were not able to rely on remembering previous answers.

Secondly the pupils were given a questionnaire with 5 sections related to: confidence in mathematics; motivation to do maths; engagement with maths; confidence with using computers and willingness to interact with computers to do maths. These questions were taken from an existing questionnaire to ensure validity and reliability (Galbraith & Haines 2000) containing scales for measuring these aspects with only slight modifications to the language made to enable them to be suitable for the age range. Each section contained 8 questions and each question used a 5-point Likert scale ranging from “Strongly agree” through to “Strongly disagree”, also represented as smiley and sad faces, respectively. Some questions were positively and others negatively worded to avoid bias. There were 40 questions in total on this questionnaire.

One week prior to the beginning of the experiment pupils were given 30 minutes to answer the pre-test and at the end of the 5 weeks they were given another 30 minutes during which to answer the post-test. The questionnaire was read and explained to the pupils by the researcher to overcome any misunderstanding. Both pre- and post-tests can be seen in Appendix 6.

7.3.1.2 Observation

Pupils were observed during both the computer game and the dice game group sessions (each session lasted for 25 minutes). Hand-written notes were used to record the observations and these were then thematically coded as shown in Table 7.11 in Section 7.6.4. In particular, the observations looked for behaviours showing pupils' motivation to play the game, engagement through the game, engagement with the game mechanic and engagement with each other (which was considered as equating to collaboration).

7.3.1.3 Click Streams

The game software automatically recorded the click streams from the pupils' gaming activities. Information could therefore be gleaned from this as to how many times each player clicked the mouse to select objects; how many times a pupil appeared to change their mind by selecting and then deselecting an object; a mean of the total key-presses made (per pupil); the mean time between object selections and the mean time for turns taken. The aim of this data was to provide further triangulation with the observation data and performance results to give a better understanding of how pupils played the game.

7.3.1.4 Focus Group

At the end of the 5 weeks focus groups were conducted with a selection of pupils from each of the experiment and control groups (computer game and dice game). The pupils were divided into focus groups according to their year of study and all ages were included (7-10 years). There were three focus groups from the experiment group (computer game) and three from the control group (dice game). This used a total of 20 pupils from the experiment group and 19 pupils from the control group, as shown in Table 7.1. Each focus group contained a mix of genders and each session lasted for 40 minutes.

Year	Computer Game		Dice Game	
	Participants NO	Age	Participants NO	Age
YEAR3	8	7-8	8	7-8
YEAR4	6	8-9	6	8-10
YEAR5	6	10	5	10

Table 7-1: Focus Group sessions Design

The aim of the focus groups was to gather information about the participants' experiences playing the game and to ask about their views on the game and the effect of playing. The questions asked can be seen in Table 7.2.

Focus Group Questions	
Computer Game	Dice Game
1. What did you think of the spider computer game?	1. What did you think of the Dice maths game?
2. When you played the game for the first time, what did you think? 3. When you played the game last time, what did you think? 4. Has the game changed how you do maths? 5. Did playing the game with someone change how you got the answer? 6. Would you have preferred to play the game, on your own or with someone? 7. What did you like best about the game? 8. What didn't you like about the game? 9. Did your group talk to other groups that were playing at the same time? If so, what about?	

Table 7-2: Focus Group Questions

7.3.1.5 Interviews

Semi-structured interviews were conducted at the end of the 5 weeks with the teachers in order to gather their views on the effectiveness of the games. Six questions were given to 3 teachers who had responsibility for each of years 3, 4 and 5. In particular, the questions aimed to ask about the impact of playing the games on pupils' maths performance as follows:

- Motivation to solve maths problems.
- Willingness to contribute in class.

- Engagement in maths activities.

The interviews were transcribed and a sample of the transcriptions can be seen in Appendix 7.

7.4 Pilot Study

Prior to conducting the full study a pilot study was run to test the experimental design and the data collection methods. The aim was to mimic the final study before it was run to ensure the validity of both methods and procedure of the study (Robson, 2002).

7.4.1 Participants

The pilot study involved 6 pupils of different ages (between 7 and 10 years old), gender and mathematics abilities. Three sessions were run with pairs of children; the first group contained two boys, the second two girls and the third was of mixed gender.

7.4.2 Procedure

As was intended for the full study, each child completed the pre- and post-tests with the researcher reading and explaining each question as needed. It was important to check that the language of the questions was suitable for the ages of the children. Pupils were then observed playing both types of games, the computer game and the dice game. At the end of the study the children were interviewed about their views on

both collaborative games. Pictures of one of the pilot study sessions can be seen in Figure 7.8 below.

Figure 7-8: Participants playing both games during pilot study

7.4.3 Findings

The pupils were able to answer the maths assessment test without any difficulty in understanding the questions but a few changes were required to be made to the questionnaire which examined confidence and motivation in doing maths and using computers in order to make them easier to understand.

Participants showed lots of collaboration, engagement and interaction during the sessions, as can clearly be seen in Figure 7.8 and nobody appeared to have any difficulty in playing either game.

Pupils did request that the computer game settings were amended to make their turn taking clearer so that their turn was identified using their name.

The next section presents the results of the full study.

7.5 Full Study

7.5.1 Participants

The experiment was conducted at a local primary school (School A, see Table 3.1 in Chapter 3) on a sample of 50 pupils who were selected from years 3, 4 and 5 (ages 7-10) in Key Stage 2. The participants were of mixed gender with a roughly equal split between boys and girls over the age range. Pupils were divided into two groups, one to play the computer game with 27 pupils (12 pairs) and one for the control group (Dice Game) with 23 pupils (11 pairs as pupils moved between pairs and one pupil left early). Pupils were chosen so that each group had varying levels of mathematical ability and also included some pupils who had low motivation for learning mathematics, as reported by the teacher, as well as more motivated students.

7.5.2 Procedure

One week prior to playing the game each participant took part in the pre-tests as described in section 7.3.1.1.

Each group played the collaborative maths game for 25 minutes per session, with one session per week for the duration of 5 weeks.

During the experiment observations were performed (see section 7.3.1.2), and behaviours recorded for later thematic analysis, in the same way as was described in Chapter 5. The game software also logged click streams from players, as described in section 7.3.1.3, for later analysis of behaviours.

Following the 5-week experiment, post-tests, focus groups and interviews were conducted (see sections 7.3.1.4 and 7.3.1.5) with both groups, to assess changes in performance and levels of interest and engagement in the game and to gather opinions related to whether the pupils felt the games had helped their maths problem solving.

7.6 Experiment Results and Analysis

Game play data from both experiments were analysed, looking for evidence of collaboration, engagement with the game and engagement with the game mechanic, as well as whether any changes in mathematics ability or attitudes towards learning maths had taken place. Data from the control group (dice game) were also compared with data from the experiment group (computer game) to see if there were any differences between the two. The data are presented and analysed in the following sections.

7.6.1 Statistical Analysis (SPSS)

The pre and post-test scores for each student in the groups were analysed, as were the pre and post-experiment attitude scores. Initially an analysis was undertaken using SPSS Wilcoxon test because the data do not meet the requirements for a parametric test. The data were not normally distributed and the questionnaire data were measurements on an ordinal scale.

The Wilcoxon test value for the difference between pre- and post-experiment maths scores for the experiment group was 0.706, which indicates that there was no significant change in the mathematics test scores for this group as a whole. Similarly the Wilcoxon test value for the control group was

0.643, which again shows that no significant change had taken place.

Wilcoxon test values for pre- and post-attitude regarding mathematics confidence for the experiment group showed no significance (0.241). However the corresponding control group result for this was 0.024 which indicates a significant change between the pre- and post-attitude of mathematics confidence in this group. This significant result indicates that a well-designed game does not necessarily need to be computer-based to enhance confidence in ability; conventional games could be equally useful in the classroom. The control group results are discussed further in the next sections.

On the other hand it was clear from direct observation of the scores data that the individuals with high pre-test scores would not have been expected to improve. It was also clear that several of those with low pre-test scores had improved their scores. Within these groups the situation was more variable. Thus it was decided to compare individual participants results independently as a percentage change to see if there were noticeable trends either within or between groups.

7.6.2 Pre- and Post-Tests for Mathematics Ability

Tables 7.3 and 7.4 show the results of the mathematics ability pre- and post-test scores for both groups (experiment group and control group). In this section an analysis of the results is presented in terms of the test scores achieved and the number of questions skipped in the pre- and post-test. The pre- and post-test scores are presented in terms of improvement, or not, of each score by the end of the 5 weeks of playing the game. The data was analysed as a percentage change – the difference in score as a percentage of the pre-test score. This will emphasise changes in low achievers' scores over the high achievers, thus allowing for the high achievers in the pre-test being unable to improve their scores.

User ID	Pre Test	Post Test	% change
P1	40	40	0
P2	40	39	-3
P3	40	34	-15
P10	40	39	-3
P44	34	28	-18
P39	33	34	3
P4	32	18	-44
P8	30	34	13
P9	29	22	-24
P27	29	33	14
P11	28	29	4
P41	25	23	-8
P42	25	25	0
P43	25	14	-44
P40	21	33	57
P32	21	8	-62
P21	19	12	-37
P28	17	15	-12
P22	16	20	25
P13	14	24	71
P24	14	12	-14
P5	13	20	54
P23	11	16	45
P12	9	23	156
P29	6	22	267
P31	6	23	283
P30	3	4	33
Mean			27
Std. Deviation			84

Table 7-3: PRE and POST-TEST SCORES FOR MATHEMATICAL ABILITY (Experiment Group)

User ID	Pre Test	Post Test	% change
P15	40	34	-15
P50	36	18	-50
P6	34	31	-9
P14	34	36	6
P19	33	29	-12
P33	32	27	-16
P18	29	15	-48
P7	28	35	25
P45	28	28	0
P48	26	28	8
P47	25	25	0
P16	23	31	35
P17	22	22	0
P46	22	20	-9
P35	20	30	50
P37	20	20	0
P49	20	28	40
P34	17	16	-6
P38	17	25	47
P20	13	15	15
P25	13	18	38
P26	10	22	120
P36	9	4	-56
Mean			7
Std. Deviation			38

Table 7-4: PRE and POST-TEST SCORES FOR MATHEMATICAL ABILITY (Control Group)

Looking at the tables it can be seen that there was a noticeable variation in the scores within both groups across the whole experiment. Those in the top half of either table would expect to have percentage changes near to zero and those at the bottom might be expected to have the largest changes. Pupils who used the computer game had a median percentage improvement of 0 (Table 7.3) and those that played the dice game showed a median percentage improvement of 0 (Table 7.4). These figures therefore show that the median improvement in maths ability for both groups was the same but that there was a much greater variance in the data over the computer game group. As was noted before, some participants (four from the experimental group and one from the control group) had a maximum pre-test score of 40 and so could not improve their scores in the post-test. In addition three of the pupils playing the computer game got notably worse scores in the post-test, as did one of those from the control group. Indeed, a number of individuals' results showed reductions in their performance while others mostly at the lower end of the pre-experiment score range appeared to have greatly improved. These more obvious differences are highlighted in Tables 7.3 and 7.4, in green for those who showed improvement and in red for performances that decreased and further analysis of these individuals is described in Section 7.7 A separate analysis of the decisions to answer or skip questions in the maths ability tests before and after the experiment can be seen in Figure 7.9 and 7.10. It was thought that these data may give an indication of pupils' motivation and confidence towards trying to answer questions. Clearly there is some decrease in numbers of questions skipped from pre- to post-test in some cases but this is not so for all who skipped questions and in some cases pupils skipped more questions in the post-test than in the pre-test. This will be revisited in Section 7.7.

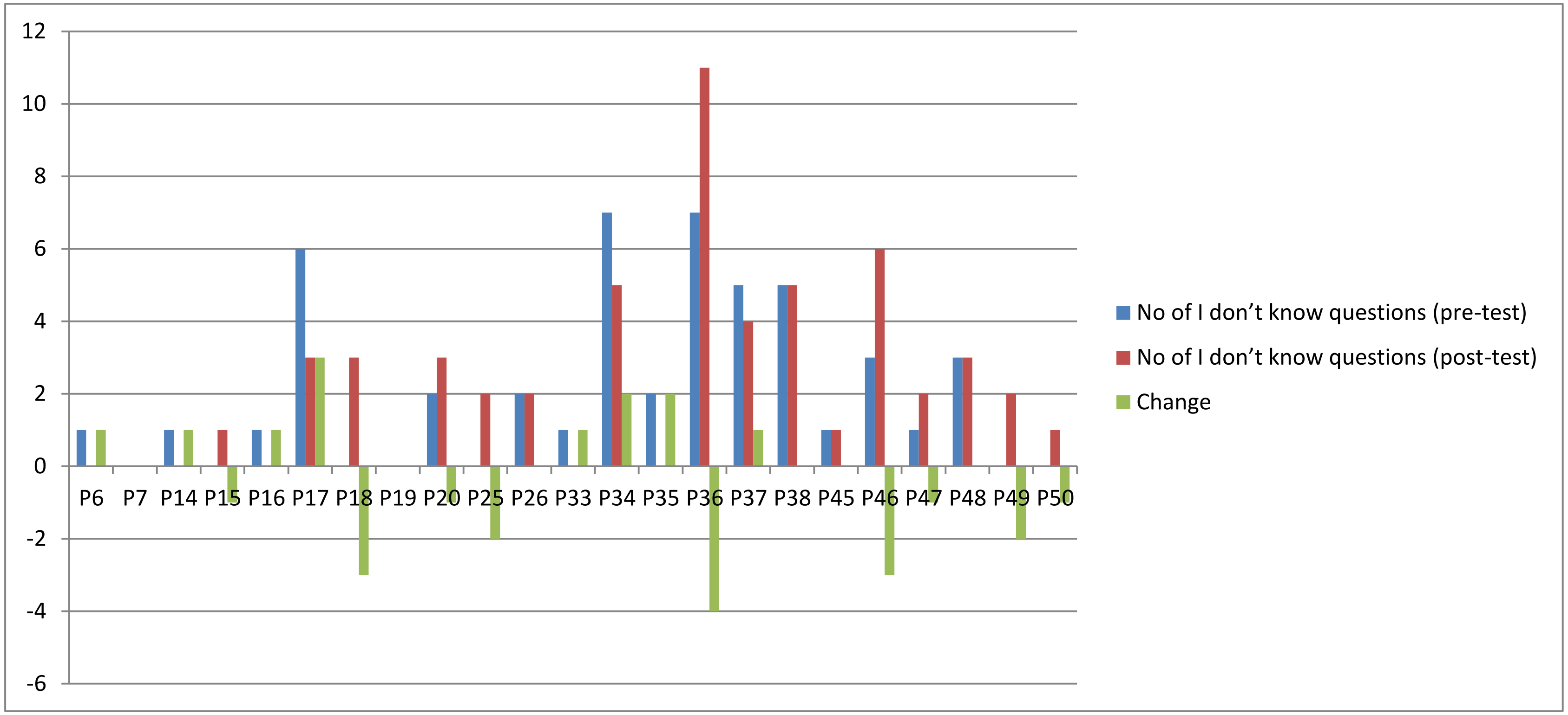


Figure 7-9: NUMBER OF QUESTIONS SKIPPED IN PRE- AND POST-TEST CONTROL GROUP (Dice Game)

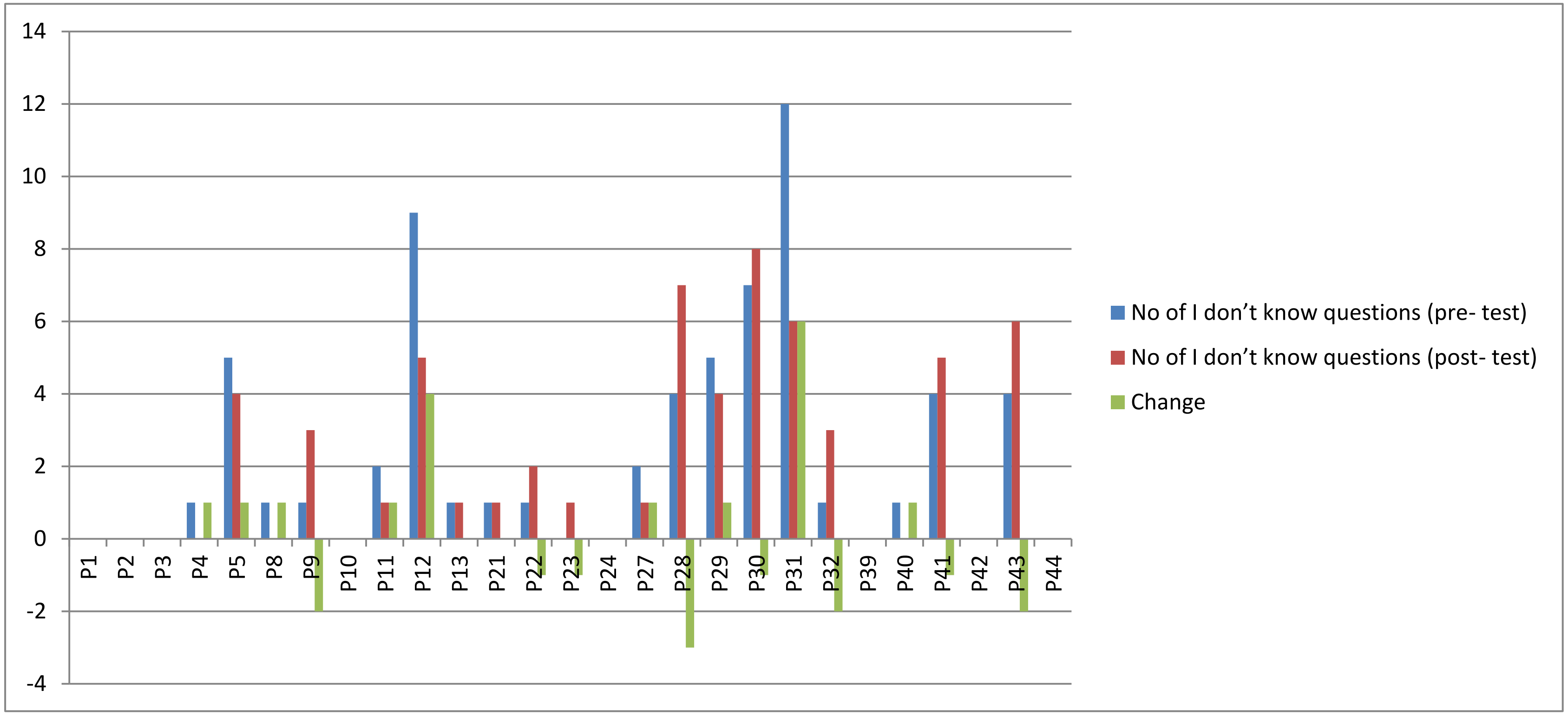


Figure 7-10: NUMBER OF QUESTIONS SKIPPED IN PRE- AND POST-TEST EXPERIMENT GROUP (Computer Game)

7.6.3 Pre- and Post- Experiment Mathematics and Computer Attitudes Questionnaire

This section presents the results of the questionnaire that asked about attitudes towards learning maths and using computers (described in section 7.3.1.1).

The questionnaire statements were scored from 1 to 5 where 1 represented a strongly negative statement (e.g. strongly agreeing with a negative statement or strongly disagreeing with a positive statement) and 5 represented a strongly positive statement. Examples of the questionnaire results are shown in Appendix 8.

As explained in section 7.6.1 the data from the 27 pupils who took part in the experiment group and 23 pupils who were in the control group were analysed using SPSS but no significant difference was found between experiments in terms of attitudes measured before and after the experiment, with one exception. The control group was found to have significantly improved in confidence in their attitude towards learning maths.

In order to look for reasons where the data between groups were not significantly different, the individual differences from the mean for the highlighted pupils in Tables 7.3 and 7.4 their data was re-examined in detail. The attitude scores for these individuals were then compared to the average attitude of all the pupils' from their pre-experiment score and these are illustrated in tables 7.5 – 7.8 below.

Tables 7.5 and 7.6 show a set of pupils' attitude questionnaire results for those who had the greatest improvement in their maths post-tests compared to their pre-test and were trained in the experimental group (Table 7.5) or the control group (Table 7.6). It is clear that the mean percentage for the differences between the pre and post-attitude rankings show no general trend with changes in attitude scores between -11% and 49% for those in the experiment group. However, there is a gradual increase in the mean difference of the results in varying percentages at all questionnaire sections with 9%, 20%, 24%, 25% and 33% for the control group as illustrated in Table 7.6.

Participants	Gender	Year of Study	Teacher assessed maths level	Mathematics Confidence		Change %	Mathematics Motivation		Change %	Mathematics Engagement		Change %
				Pre	Post		Pre	Post		Pre	Post	
P12	Girl	Y3	MA	17	18	6%	15	11	-26%	12	17	42%
P29	Boy	Y4	MA	20	15	-25%	22	22	0	12	24	100%
P31	Girl	Y4	LA	20	17	-15%	30	31	3%	25	26	4%

Computer Confidence		Change %	Computer Mathematics-Interaction		Change %
Pre	Post		Pre	Post	
12	16	33%	12	14	17%
26	24	-8%	16	18	13%
29	34	17%	32	34	6%

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence	Mathematics Motivation	Mathematics Engagement	Computer Confidence	Computer Mathematics-Interaction
				Changes %	Changes %	Changes %	Changes %	Changes %
P12	Girl	Y3	MA	6%	-26%	42%	33%	17%
P29	Boy	Y4	MA	-25%	0	100%	-8%	13%
P31	Girl	Y4	LA	-15%	3%	4%	17%	6%
Mean				-11%	-8%	49%	14%	12%

Table 7-5: The attitude change for the pupils selected from the experiment group whose pre and post-test scores had improved (see Table 7.3) and their mean attitude changes

Attitude differences for maths confidence, motivation and engagement and for computer confidence and computer maths-interaction can be seen. Those pupils with the highest confidence and engagement in maths are highlighted in green

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence		Change %	Mathematics Motivation		Change %	Mathematics Engagement		Change %
				Pre	Post		Pre	Post		Pre	Post	
P26	Girl	Y3	LA	16	25	56%	22	32	45%	24	28	17%
P35	Girl	Y4	MA	24	28	17%	26	25	-4%	22	24	9%
P38	Girl	Y4	MA	16	16	0%	17	20	18%	18	31	72%

Computer Confidence		Change %	Computer Mathematics-Interaction		Change %
Pre	Post		Pre	Post	
36	38	6%	36	34	-6%
30	29	-3%	24	30	25%
29	36	24%	22	34	55%

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence	Mathematics Motivation	Mathematics Engagement	Computer Confidence	Computer Mathematics -Interaction
				Changes %	Changes %	Changes %	Changes %	Changes %
P26	Girl	Y3	LA	56%	45%	17%	6%	-6%
P35	Girl	Y4	MA	17%	-4%	9%	-3%	25%
P38	Girl	Y4	MA	0%	18%	72%	24%	55%
Mean				24%	20%	33%	9%	25%

Table 7-6: The attitude change for the pupils selected from the control group whose pre- and post-test scores had improved (see Table 7.4) and their mean attitude changes

Attitude differences for maths confidence, motivation and engagement and for computer confidence and computer maths-interaction can be seen. Those pupils with the highest confidence and engagement in maths are highlighted in green

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence		Change %	Mathematics Motivation		Change %	Mathematics Engagement		Change %	Computer Confidence		Change %	Computer Mathematics-Interaction		Change %
				Pre	Post		Pre	Post		Pre	Post		Pre	Post		Pre	Post	
P4	Girl	Y3	HA	25	27	8%	37	36	-3%	28	26	-7%	31	29	-6%	25	36	44%
P32	Girl	Y4	LA	19	29	53%	22	26	18%	31	30	-3%	35	28	-20%	28	34	21%
P43	Girl	Y5	MA	23	26	13%	27	29	7%	28	24	-14%	35	31	-11%	34	31	-9%

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence	Mathematics Motivation	Mathematics Engagement	Computer Confidence	Computer Mathematics-Interaction
				Changes %	Changes %	Changes %	Changes %	Changes %
P4	Girl	Y3	HA	8%	-3%	-7%	-6%	44%
P32	Girl	Y4	LA	53%	18%	-3%	-20%	21%
P43	Girl	Y5	MA	13%	7%	-14%	-11%	-9%
Mean				25%	7%	-8%	-12%	19%

Table 7-7: The attitude change for the pupils selected from the experiment group whose pre and post-test scores had decreased (see Table 7.3) and their mean attitude changes.

Attitude differences for maths confidence, motivation and engagement and for computer confidence and computer maths-interaction can be seen. Those pupils with the lowest confidence and engagement in maths are highlighted in red

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence		Change %	Mathematics Motivation		Change %	Mathematics Engagement		Change %	Computer Confidence		Change %	Computer Mathematics-Interaction		Change %
				Pre	Post		Pre	Post		Pre	Post		Pre	Post		Pre	Post	
P18	Girl	Y3	MA	40	39	-3%	36	36	0%	32	28	-13%	36	32	-11%	36	36	0%
P36	Girl	Y4	MA	36	28	-22%	40	28	-30%	28	28	0%	40	40	0%	38	36	-5%
P50	Boy	Y5	MA	31	35	13%	31	34	10%	26	22	-15%	33	25	-24%	36	34	-6%

Participants	Gender	Year of Study	Teacher level	Mathematics Confidence	Mathematics Motivation	Mathematics Engagement	Computer Confidence	Computer Mathematics-Interaction
				Changes %	Changes %	Changes %	Changes %	Changes %
P18	Girl	Y3	MA	-3%	0%	-13%	-11%	0%
P36	Girl	Y4	MA	-22%	-30%	0%	0%	-5%
P50	Boy	Y5	MA	13%	10%	-15%	-24%	-6%
Mean				-4%	-7%	-9%	-12%	-4%

Table 7-8: The attitude change for the pupils selected from the control group whose pre and post-test scores had decreased (see Table 7.4) and their mean attitude changes

Attitude differences for maths confidence, motivation and engagement and for computer confidence and computer maths-interaction can be seen. Those pupils with the lowest confidence and engagement in maths are highlighted in red

Tables 7.7 and 7.8 show pupils' attitude questionnaire results for those whose maths scores had reduced most in their post-test compared to their pre-test results. Table 7.7 – for the experiment group – indicates a variation in the results with increases and decreases between the pre- and post-rankings for all the questionnaire sections. However, the mathematics confidence shows the greatest increase percentage mean with 25% while computer confidence showed the greatest decrease with -12%.

Moreover, Table 7.8 shows decreased mean ranking percentages for all the questionnaire sections for the control group (between -4% and -9%).

Furthermore, the mathematics engagement section displays interesting results where there is a notable increase in the average percentage attitude ranking for those who got the highest percentage improvements in the maths post-test whereas there is a decrease in the average percentage attitude ranking for those who had largest percentage reduction in their maths post-test results. This can indicate a notable relation between pupils engagement with mathematics and their performance in the maths test and this is apparent based on pupils attitude questionnaire scales. The results of this section will be commented on again in the Section 7.7

discussion by linking it with the evidence from the other measures.

7.6.4 Observation

The written observation notes were coded for pupils' behaviours to be analysed thematically in regards to several themes namely Motivation (M); Engagement with the game mechanic (EM); Engagement through the game (EG), and Engagement with each other (EO) which equates to collaboration. Each theme will be clarified through a range of behaviours that occurred throughout. The pupils' motivation can be seen as evidenced by their enthusiasm, challenge statements and goal seeking behaviours in trying to solve the maths problems. Engagement with the game mechanic is based on concentration on learning content (maths) through different actions like collecting objects in order to solve the problems that have been integrated in the game mechanic and thus to be more effective for learning rather than just playing. Pupils in both experiment and control groups exhibited lots of interaction behaviour while playing, which equates to engagement through the game. These behaviours involved having fun, gesturing and physical movement or engagement with each other through collaborating by conversation, sharing knowledge and asking questions. Furthermore, each theme is analysed from both positive and negative perspectives (e.g.

showing signs of enthusiasm is a positive and showing signs of boredom is a negative perspective).

Table 7.9 below illustrates the observation analysis of a number of relevant behaviour occurrences during the activity for both groups. This will be compared in discussion in Section 7.7. Examples of full observation notes and thematic analysis are shown in Appendix 9. The final two columns indicate when the value is noticeably greater for the experiment compared to the control and vice versa.

Code	NO OF OCCURRENCES Computer Game (Experiment)	NO OF OCCURRENCES Dice Game (Control)	Frequency per player (Experiment)	Frequency per player (Control)	Expt. Freq./Control Freq.	Control Freq./Expt. Freq.	Experiment compared to control	Control Compared to experiment
Confidence	21	10	0.78	0.43	1.79	0.56	1.8x	
Enthusiasm	21	35	0.78	1.52	0.51	1.96		2.0x
Goal seeking	9	20	0.33	0.87	0.38	2.61		2.6x
self-correction	4	0	0.15	0.00	0.00	0.00		
Challenge	24	22	0.89	0.96	0.93	1.08		1.1x
Individual effort	10	4	0.37	0.17	2.13	0.47	2.1x	
Game story	1	0	0.04	0.00	0.00	0.00		
Fun	5	5	0.19	0.22	0.85	1.17		1.2x
Concentration	14	20	0.89	0.87	1.02	0.98	1x	
Moving quickly	0	4	0.00	0.17	0.00	0.00		
Collecting objects	6397	319	237.00	14.00	17.00	0.06	17x	
Manipulating objects	1	3	0.04	0.13	0.28	3.52		3.5x
Gesture	2	0	0.07	0.00	0.00	0.00		
Observing	4	0	0.15	0.00	0.00	0.00		
Physical Movement	19	18	0.70	0.78	0.90	1.11		1.1x
Conversation	22	28	0.81	1.22	0.67	1.49		1.5x
Sharing knowledge	10	19	0.37	0.83	0.45	2.23		2.2x
Instruction	37	15	1.37	0.65	2.10	0.48	2.1x	
Collaboration	11	7	0.41	0.30	1.34	0.75	1.3x	
Arguing	10	5	0.37	0.22	1.70	0.59	1.7x	
Help from the researcher	9	5	0.33	0.22	1.53	0.65	1.5x	
Questioning	10	14	0.37	0.61	0.61	1.64		1.6x
Aggression	2	0	0.07	0.00	0.00	0.00		
Control	5	6	0.19	0.26	0.71	1.41		1.4x
Quiet	12	4	0.44	0.17	2.56	0.39	2.6x	
Random collecting	0	0	0.00	0.00	0.00	0.00		
Looking around	1	1	0.04	0.04	0.85	1.17		1.2x
Distracted	2	2	0.07	0.09	0.85	1.17		1.2x
Ignoring	2	5	0.07	0.22	0.34	2.93		3x
Speak quietly	1	1	0.04	0.04	0.85	1.17		1.2x
Hasty	4	0	0.15	0.00	0.00	0.00		
Bored Face expression	0	2	0.00	0.09	0.00	0.00		
Follow without thinking	6	0	0.22	0.00	0.00	0.00		
Faulty collecting	3	0	0.11	0.00	0.00	0.00		
Apparently random collecting	5	0	0.19	0.00	0.00	0.00		
Frustration	6	3	0.22	0.13	1.70	0.59	1.7x	
Angry	1	0	0.04	0.00	0.00	0.00		

Table 7-9: Observation Thematic Analysis Codes

Codes highlighted are those particularly relevant to the cases discussed in Section 7.7.

7.6.5 Click Stream

This section provides (in-game) logged activity results for the experiment group during game play. This data can provide useful information on how individuals performed for each session in general in order to provide a more detailed analysis. Examples of click stream data are attached in Appendix 10. However, the performance results for the pupils who got the highest and lowest post-test marks in particular are presented in the tables below.

Participants	date	mean keypresses	mean time between selections (s)	mean turn time (s)
P32	20/06/2014	40.5	6.4	19.4
	26/06/2014	48.6	6.1	19.6
	03/07/2014	50.3	7.9	22.2
	10/07/2014	58.2	9.8	26.2
	15/07/2014	73.6	5.4	18.8
P43	25/06/2014	53.5	8.0	22.0
	02/07/2014	59.9	4.9	14.1
	09/07/2014	69.9	5.2	13.8
	16/07/2014	74.6	6.7	19.7
P4	19/06/2014	68.8	9.4	36.8
	26/06/2014	80.1	6.9	20.6
	03/07/2014	76.8	10.5	32.8
	10/07/2014	76.1	6.8	19.5
	16/07/2014	71.5	10.2	26.5

Table 7-10: Key press data for those who had the greatest decrease in maths score in the post-test.

Participants	date	mean keypresses	mean time between selections (s)	mean turn time (s)
P29	26/06/2014	91.7	6.5	21.2
	03/07/2014	100.8	18.7	44.7
	10/07/2014	69.2	12.1	26.4
	15/07/2014	68.9	10.7	22.1
P12	25/06/2014	44.5	3.7	15.5
	10/07/2014	65.1	12.7	33.1
	15/07/2014	85.8	8.8	31.8
P31	20/06/2014	31.5	9.2	22.1
	03/07/2014	71.8	7.0	21.2
	10/07/2014	69.3	7.0	18.2
	15/07/2014	72.3	3.9	12.4

Table 7-11: Key press data for those who had the greatest increase in maths score in the post-test.

The overall results appear to vary among the players' game play behaviours for both those sets of data. There is thus no relevant correlation between these behaviours and the post-test outcome.

Participants	Sessions	Select	Deselect
P32	1	16	0
	2	35	0
	3	68	1
	4	52	3
	5	77	12
Sum		248	16
Mean over Training sessions		50	8
P43	1	34	0
	2	93	0
	3	66	5
	4	106	10
Sum		299	15
Mean over Training sessions		75	4
P4	1	13	1
	2	42	6
	3	50	8
	4	49	2
	5	39	0
Sum		193	17
Mean over Training sessions		39	3

Table 7-12: Logged Data for Select & Deselect action for players whose post-test mark had decreased the most.

In terms of those who did significantly worse in their post-test marks, Table 7.10 illustrates that two pupils were more confident to play in the beginning of the sessions, making choices quickly, while by the end of the last sessions their confidence to make a decision seems to be lower as the number of deselect choices has increased. However, the last player shown in Table 7.12 started out with a lack of conviction in their choices but ended up playing more quickly without making any correction of their choices.

Participants	Sessions	Select	Deselect
P29	1	44	5
	2	32	4
	3	55	4
	4	62	5
Sum		193	18
Mean over Training sessions		48	5
P12	1	79	9
	2	29	2
	3	33	7
Sum		141	18
Mean over Training sessions		47	6
P31	1	17	0
	2	56	1
	3	46	2
	4	73	2
Sum		192	5
Mean over Training sessions		48	1

Table 7-13: Logged Data for Select & Deselect action for players whose post-test mark had increased the most

Table 7.13 shows that two players who had increased their post-test score the most (P29 and P12) showed a slight improvement in their selection performance by raising their playing rate. This may be due to them having increased familiarity with how to play the game or with their confidence which also leads to a slight reduction in their number of de-selections. Finally, of the players who improved their maths scores P31 performed differently remaining quite quick and confident in her play throughout.

7.6.6 Focus Groups

The focus group sessions recordings were transcribed. Each question answer was anonymised. The transcriptions were then coded using a thematic analysis approach, which resulted in four distinct themes namely motivation, engagement with the game mechanic, engagement through the game and engagement with each other. This included both positive and negative behaviours in each theme. Table 7.14 displays the coded results for both computer game and dice game groups.

Code	Meaning	NO OF OCCURRENCES Experiment Group	NO OF OCCURRENCES Control Group	Frequency Experiment Group - FEG	Frequency Control Group - FCG	FEG/FCG	FCG/FEG	Experiment higher	Control Higher
fr	Frustration	19	46	0.95	2.42	0.4	2.5		2.5
e	Enthusiasm	81	86	4.05	5	0.8	1.2		1.2
ch	Challenge	35	22	1.75	1.16	1.5	0.7	1.5	
hr	Help from the researcher	0	1	0	0.05	0	0		
f	Fun	5	4	0.25	0.21	1.2	0.8	1.2	
cf	Confidence	29	10	1.45	0.53	2.7	0.4	2.7	
gg	Game story	25	16	1.25	0.84	1.5	0.7	1.5	
go	Goal seeking	17	16	0.85	0.84	1	1		
cl	Collaboration	32	22	1.6	1.16	1.4	0.7	1.4	
s	Sharing knowledge	8	5	0.4	0.26	1.5	0.7	1.5	
ie	Individual effort	17	12	0.85	0.63	1.3	0.7	1.3	
cn	Concentration	6	1	0.3	0.05	6	0.2	6	
arg	Arguing	2	1	0.1	0.05	2	0.5	2	
co	Collect objects	8	6	0.4	0.32	1.3	0.8	1.3	
ag	Aggression	2	0	0.1	0	0	0		
c	Conversation	1	0	0.05	0	0	0		
an	Anger	1	0	0.05	0	0	0		

Table 7-14: Focus Group Coding Results

Codes highlighted are those particularly relevant to the cases discussed in Section 7.7.

It was clear that pupils' answers and opinions for each question varied based on their experience taking part in different groups. The representative sample table of transactions for both groups is shown in Appendix 11. Example answers from each group are presented below. The analysis of the results indicated that there was a difference between the group impression of seeing and playing the games for the first time where pupils felt more frustrated playing the dice game with a 2.5 times greater frequency than for the computer game.

7.6.6.1 Dice Game

"Unfair. People like laptops more. You know that children nowadays like electronic devices. We really want to do the computer game but we have to do the dice game. Sometimes when you do that for a long time it becomes boring."

"It sounded fun, and then became complicated". "Frustrating"

On the other hand, pupils were more motivated to practice maths by playing the computer game with a 1.5 times greater frequency for positive comments about this than for those playing the dice game. This is illustrated by the following comments which show lots of examples of statements relating to challenge and engagement from those who played the computer game.

7.6.6.2 Computer Game

"Good because you just have four turns to solve the problem"

"I think it's fantastic because you try a challenge with something and you get to different levels"

"I think it's quite good because you had to make different sums and there is only one way around it, and you can only use four fights [chances]"

When focusing on the influence of each game based on the pupils' opinions during the interview sessions encouraging views on the impact of the game on their mathematics performance appeared.

7.6.6.3 Computer game

"It's changed my maths because now I can add bigger numbers easily. It's let me get more confident"

"I think it's helped me with take away; normally I do not know take away when I start the game but then my take away is getting faster"

"Usually I do not like maths but after playing the game I start to like maths more and I get better doing maths"

"I think I am getting better in maths because the other day the teacher in the class asked us to do some maths calculation to 51 and we just had a certain amount of numbers, and I have done it quicker than usual because I was remembering what I was doing in the computer game"

7.6.6.4 Dice Game

"It has changed my way because then we was [sic] doing maths through different materials"

"I used to be scared in maths because I did not know how to do times tables but now I know the answer for most of my times tables"

"First I was not confident to ask questions in maths because I do not like to participate in maths but now I really do put my hand up"

"The things that I learned already in class - this can help me"

"I think it's better than the normal maths lesson because we had to use different dices doing subtraction which made me understand subtraction more than the class"

But in this group there were negative comments – for example:

"I do not think it helped me at all"

It was clear that the computer game experience had greater influence on pupils' confidence positively compared to the dice game as this group only had positive comments whereas the dice game respondents a number of negative statements similar to the above. This is confirmed in Table 7.14 where the confidence code appears with a 2.7 times greater frequency for the computer game than the dice game.

Moreover, it was noticed also that pupils engaged more with each other through collaboration in the computer game with 1.4 times greater frequency in the computer game players than with the dice game players where pupils felt more confusion over how to work as a team. The pupils in the experiment group indicated that they concentrated more on reaching the goal by working as team playing the computer game than the dice game with a 6 times greater frequency for this group than that of the dice game players.

Finally, pupils in each group expressed sadness at the last session of the game because they had experienced lots of fun and had lots of enthusiasm for the games.

7.6.7 Teacher Interviews

The teachers' views were really important and play an essential role within the educational environment of the pupils. The selected interview transcription of the teachers' answers to the questions can be found in Appendix 7. In this section particularly pertinent comments are presented:

The teachers indicated that there were no differences between the experiment or control groups after the sessions, however, they confirmed that there was a difference between those who took part in either activity and the pupils who did not take part in the study. The teachers noticed the difference through lots of positive behaviours especially the following:

- Motivation to solve problems.
- Willingness to contribute in class.
- Responsiveness to others' answers.
- Engagement in maths activities.

Examples of pertinent teacher comments:

The Year 3 teacher said**,** "*All the children in the class have shown increased engagement in activities. They discuss each other's answers and build upon them. There are many more hands up in the whole class and children are more confident with their answers*"

The whole of Year 3 participated in the study and their teacher confirmed the improvement was with the whole class.

The Year 4 teacher said, "*With problem solving, children are more willing to tackle problems. They answer more mental questions using hands up; they have become quicker at this. They are more engaged in maths and problem solving lessons (they get started more quickly and independently)*"

The Year 5 teacher said, "*There was no difference between the two groups, however, there was a difference between children taking part and those not taking part though [Motivation to solve problems and engagement in maths activities]. Children are more willing to persevere with problems in class. Children listen more and are answering questions more in class.*"

It is worth mentioning that although pupils were selected from Y4 and Y5 especially as being less motivated and engaged to learn mathematics their teachers have confirmed the occurrence of positive change after the study as mentioned above.

Finally, teachers confirmed that although pupils were beginning to get ready for their holidays they were still showing lots of improvement in their attitudes such as confidence and perseverance during the maths classes. They believed that without any doubt using this kind of activity in the long term can have a positive impact on pupils' performance in maths and their attitudes towards school.

The Year 3 teacher said, "*Children have shown more perseverance in class whereas before they would have given up.*"

The Year 5 teacher said, "*Unfortunately it is quite late in the year so it has been difficult to determine whether the children's attainment has increased although there has been an improvement in attitude.*"

The teachers were all convinced of the value of this activity and all their comments reinforced the view that it was helpful to involve such a variety of activities in their teaching.

7.7 Discussion

The central aim of this study was to illustrate how the potential of both the collaboration in playing the game and the engagement with the game mechanic can play a useful role in promoting pupils' motivation and achievement in solving mathematics problems at Key Stage 2.

It was apparent from the statistical analysis of the data for the whole of each group using SPSS that no significant overall changes had occurred in the overall group performance in the post-test compared to the pre-test. Conversely, when the performance of the lower achievers in the pre-test scores (below average for the groups) is analysed it is clear that a notable change were noticed among the results as shown in tables 7.15 and 7.16 below.

User ID	Pre Test	Post Test	% change
P30	3	4	33
P29	6	22	267
P31	6	23	283
P12	9	23	156
P23	11	16	45
P5	13	20	54
P13	14	24	71
P24	14	12	-14
P22	16	20	25
P28	17	15	-12
P21	19	12	-37
P40	21	33	57
P32	21	8	-62
Mean	13	18	67
Standard deviation			107

Table 7-15: PRE- and POST-TEST Scores for pupils with lower than average pre-test scores from the Experiment Group

User ID	Pre Test	Post Test	% change
P36	9	4	-56
P26	10	22	120
P20	13	15	15
P25	13	18	38
P34	17	16	-6
P38	17	25	47
P35	20	30	50
P37	20	20	0
P49	20	28	40
Mean	15	20	28
Standard deviation			48

Table 7-16: PRE and POST-TEST Scores for pupils with lower than average pre-test scores from the Control Group

It was known that pupils who had a high level of pre-test performance could not improve their scores much if at all. However, if only those who scored less than the average are taken into consideration the situation looks significantly different. Table 7.15 illustrates the results of the mathematics pre- to post-test change for 13 pupils who had below average pre-test scores and took part in the experiment group for 5 weeks. The average pre-test score was 13 while it is interesting to highlight 67 +/- 107% as a mean percentage improvement within this group. On the other hand, Table 7.16 indicates the mathematics pre- and post- test results for 9 pupils out of the 23 who took part in the control group for 5 weeks who had below-average pre-test scores. It is shown that the average pre-test score for this group was 15 and that there was a 28 +/- 48% mean percentage of improvement.

The results presented in Table 7.15 and Table 7.16 show a large number of pupils who improved notably. However, it should be noticed that there were also cases where pupils from each group got a notably worse score in the post-test. The performance results for the students are examined further below in more detail in combination with the behaviours and attitudes data evidence that was gathered through the other methods in this study.

7.7.1 Behaviours and Attitudes

The evaluation of the individual data is here discussed in relation to the individual's behaviours and attitudes in relation to various factors including collaboration, engagement and motivation.

Notable examples of different cases for pupils who trained in maths collaboratively either with the computer game as part of the experiment group or the dice game as part of the control group are presented below. The following cases show how the improvement or decline of the pupils' maths achievement may be related to the individual's playing performance and the impact of other factors – such as the willingness of their partners to collaborate.

7.7.1.1 Experiment Group

Case1

P12 collaborated in a group with four other pupils who were P11, P8 and P9. The group started off with a low level of collaboration; however, this scenario improved quickly as they continued playing the game. This was clear from the observation of pupils' behaviour where they showed lots of engagement with each other by taking, discussion and thereby shared knowledge. For example, P8 said, "What do you think? What do we need to do?" and P11 replied, "If we can pick these two numbers and then you can pick a small number we can reach 40.” However, P12 was sharing a laptop with P9 who was highly motivated and more capable in doing maths. P12 seemed to interact with the game mechanic but more indirectly through collaboration and sharing the experience with the more capable pupil P9. This can have contributed to the increase in P12’s performance by having gained lots of information from the other they worked with.

Case2

P32 scored 21 in the pre-test which would be classified as medium ability but the teacher had identified P32 among the whole class as a low ability student. It is likely therefore that their pre-test score was somewhat higher than their normal performance.

P32 and P31 originally played as a team but this combination failed to show any sort of engagement either between each other or with the game.

Later P32 and P27 played together. P27 was considered by the teacher as middle ability within the whole class. P27’s score in the post-test improved slightly over the pre-test; however, both scores were at the right level for their ability. The interaction between P32 and P27 seemed to be slightly better but still they did not show lots of collaboration like taking with each other. P32 was trying to engage with the game mechanic by making lots of decisions but this did not seem to be helpful where the majority of the choices made were incorrect and based on guessing. For example, P32 kept picking small numbers and subtracting big numbers which resulted in negative numbers. These choices negatively affected P27's available choices and P27 said "You cannot do that, because I will not be able to reach the number goal in my turn". On the other hand, P27 was observed to be clearly focusing on the screen engaging with game mechanic and playing the game. For example, P27 was thinking aloud at times, saying things like "I cannot pick those numbers because we will not win in the final turn but if I take 2 and 0…" and then using his fingers to count. There was an opportunity for P32 to learn from P27 who gave good advice in the game by giving lots of instructions helping P27. From the observations, P27 was seen to have a false level of confidence in her own ability. Therefore P32's score decreased.

Case 3

P29 and P28 were collaborating as a team. Both P29 and P28 were classified as of middle-range ability among the class; however, P29 got a lower score in the pre-test which placed him below what his average should have been. P29 appeared to carefully think through all his options in order to pick the correct numbers when playing the game. This perhaps provides evidence of engaging with the game mechanic through playing the game. Conversely, P28 was observed to show an opposite approach being easily distracted showing less motivation to give attention to the game being played. P28's attitude was causing lots of argument in loud voices which lead to difficulties for P29 as a partner. Also P29 was observed to be double clicking on the space bar by mistake at times because P29 said "I did not mean to do this, I don't know how this happened". This caused P28's turn to be skipped which then caused fighting among them again. Finally, all these actions contributed to preventing P28 practicing and engaging with the activity. It is conjectured that this led to P28's post-test score being decreased by 12%. On the other hand, these obstacles encouraged P29 to be more insistent showing engagement with the activity and enabled him to present what he was capable of, thus P29 showed a large percentage improvement in the post-test of 267%.

The following quotes by P29 illustrated notable evidence of the sense of reward that could be gained from playing the game:

"(P29) I think I am getting better in maths because the other day the teacher in the class asked us to do some maths

calculations to 51 and we just had certain amount of numbers, and I did it quicker than usual because I was remembering what I was doing on the computer game".

"(P29) …it's good but it could get better if we were working with different classes, because then we can know how other people work like [sic] and we can learn from each other different ways to solve a problem, and if they're younger kids and they are stuck we can help them"

Case 4

P31 and P32 played together as a team for just one session; the case of P32 was mentioned previously in case 3 above. Then for the remaining sessions P31 worked with P30; all three participants were classified as low-ability during class maths work among the whole class of students. In the case where P31 and P32 collaborated, P32 controlled the game session more than P31 without giving any chance for P31 to contribute. However, this scenario was reversed in the other case when P31 and P30 were collaborating, in which P30 was observed as being very quiet but observant at the same time. This situation allowed P31 to express her enthusiasm more and to play the game by showing lots of engagement with the game in a hasty manner through picking lots of numbers without being careful as to whether it was a correct option to take. Later, P31 was advised to plan ahead in order to reach the desired goal and she was happy to follow this advice which contributed to engaging her deeply with the game mechanic and dominating the game. The following quotes illustrate the status of P31. P31 said "you need to hurry up before the spider gets the item". This can indicate that P31 understood the game strategy. Eventually P31 seemed to be carefully thinker and self-correcting, as is evidenced by the next quote. P31 said "basically do what we did last time but then change some numbers slightly". Finally, P31 expressed her feelings when the experiment was over as follows:

P31 said, "The game is amazing because you got better in maths" and added "I think it's fantastic because you try a challenge with something and you get to different levels" and "I think it's upset me when the experiment finished because I really enjoyed it; I really want to be at a high level". It is conjectured that because of her level of engagement with the game mechanic P31 improved more in the post-test than the whole group with a percentage change of 283%. On the other hand, P30 benefited from just being an observer of P31 and thereby increased their post test score by 33%.

7.7.1.2 Control Group

Case 1

P35 and P38 worked together as a team. Both P35 and P38 were assessed as middle-range ability in the teacher's records. The teacher reported that "normally both players behave quietly in class and do not engage with new things easily". However, this was not the case during the playing sessions where players acted differently from the teacher's expectations. It was observed that the collaboration level was really high among players which occurred during talking, discussing and sharing knowledge with each other. They showed lots of enthusiasm to play the game and motivation to reach the goal during their collaboration. For instance, both P35 and P38 were standing up looking at the numbered dice and thinking about how they could make 4. P38 said "5-1=4". P35 said "do you think we can find any other ways?" P38 said "no I do not think so because we do not have enough numbers" Then P35 shouted, "wait, wait I think I have got another two ways 6-2=4 and 4-0=4". They were observed trying several means in order to explore the quickest manner to reach the goal. Firstly, they started the round by dividing the tasks among them. Later, they decided to play together during each turn in order to be fully focused and able to reach the goal faster. This contributed to making the effort more effective. Therefore, both P35 and P38 benefited as they engaged very deeply with the game mechanic resulting in reaching an improvement of 50% for P35 and 47% for P38 in the post-tests.

Case 2

P26 played with P25 as a team. The teacher classified their abilities to be low in maths relative to the class pupils. They started the play sessions showing no confidence either in playing or collaborating with each other. This may have been due to several reasons for example P26 has difficulty communicating with others because of the language, English is not her first language, and P25 was quiet and did not interact at all with both P26 or with the game. This situation affected their ability to win in the first two sessions. Later, they were encouraged by the researcher when she was sitting with them. It seems that this new condition supported them to be able to begin playing the game themselves. Although they then tried very hard to get the right answers they appeared to interact merely by rolling the dice and moving the puzzle pieces. For example, they were rolling the number dices and they needed to make the number goal of 5 and P26 was observed taking a long time looking at the number dice while P25 was still moving the puzzle pieces while saying nothing. Then, the researcher said: "Do you think you can make 5 with the numbers you have got?" P26 said "I do not know" and P25 keep quiet. However, in the following sessions there was a large improvement in P26's interaction level where she was using her fingers to do the calculations. P26 was helping and encouraging her although they preferred to do a calculation rather than using a double which was one of the game strategies on offer. For example, they had a goal to make 12 either by adding or doubling, however, they preferred to add 6+6 to make 12 rather than doing a double. P26 showed lots of enthusiasm each time when she reached the goal by saying "yes, yes". P26 was thinking aloud and more talkative than before. P26 said "I concentrate now because if you do not concentrate you will lose". In the last session they were observed moving quickly between both games; the maths dice game and the puzzle game in order to reach the goal in the time given. For example, P25 said "How can we make 4 by subtraction?" P26 said "we need to roll the dice first in order to know our numbers". P26 added "Ok, 5 take away 1 is 4" P25 said "It's the last piece in the puzzle". They were shouting and jumping and P26 said "yes, we won!" P25 said "finally". From these observations it was clear that P26 was more engaged with the game mechanic than P25 who was being more supportive and collaborative in the game sessions. This may explain why P26 achieved the highest percentage improvement in post-test scores among the control group with 150% while P25 improved by 38% due to being a collaborator.

Case 3

P36 worked with P33 as a team. Both were identified in the middle range of ability by the teacher. It was observed that P33 showed lots more enthusiasm than P36 who failed to collaborate with P33 and refused to take any instructions from anyone, not even the researcher. This caused lots of arguments between them. For example, P36 said “give me this piece of puzzle” and P33 said “no because we need to do the maths challenge first”. P36 said “I want to do the puzzle”. Later, P33 asked the researcher to convince P36 to collaborate with him but P36 refused to cooperate. Thus, they were not talking with each other or even helping each other. For example, P33 said “we need to make 5 by using subtraction, how many ways do you think we can do it?” P36 did not give any answer but just moved the dice and said random numbers “2, 1 and 6”. P33 said “I think if we can first do adding 6+1=7 then we can use subtraction 7-2=5. This shows that P33 put in lots of individual effort to complete the game and reach the goal. Finally, it was clear that P33 was more engaged with playing the game than P36. P33 expressed his enthusiasm by saying “Yes!” each time when he found more than two ways of solving the problem or placing the appropriate piece of puzzle. This case provides a clear example where the engagement had been absent in all aspects. Firstly, lack of engagement with each other which equates to collaboration. Secondly, P36 showed to be insufficiently engaged either with the game mechanic or even just with playing the game. This appears to have been responsible for the large reduction in P36’s post-test among the control group with a drop of 56%. This situation also affected P33’s post-test score which was reduced by 16% even though he was better at playing the game and engaging than P36.

7.8 Summary

This study has fulfilled Objective 6 from Section 1.2. The evaluation of this study was against other perspectives on the role of the computer game in the learning domain. Most researchers believe that computer games are a useful learning tool where each and every subject in a school curriculum can be taught efficiently (Prensky, 2001). They have considered computer games as more usefully contributing in engaging and motivating pupils than the conventional approaches used in classrooms (Prensky, 2001, Gee, 2003; 2004; 2005; 2006; Shaffer et al., 2005; Shaffer, 2006). The key distinction between other researchers' beliefs and the results of this study will be explored more in the next chapter where the research questions will be revisited and the final conclusions made.

8 Conclusion

This thesis set out to explore the potential of using collaborative computer games to aid the learning of mathematics through problem solving for children in Key Stage 2 (7-11 year olds). A number of research questions were posed in the introduction concerning the value and limitations that were likely to be achieved. To answer these research questions it was necessary to investigate how and if children cooperate while playing games as well as ways in which problem solving was introduced in the classroom. It was necessary to integrate the learning outcome into the game play and to provide a game that was engaging to the players and thus motivating to them. For this reason background research was undertaken through the literature and by studying practice in a typical Key Stage 2 classroom. Children were also observed playing collaborative games and the way they interacted and played the game was recorded and analysed. A series of studies informed the design of a game and pilot testing of the game allowed refinements that led to a longer timescale control trial of the game designed. In order to complete a controlled test of the computer game it was also necessary to develop a non-computer based game to use with the control group. This chapter discusses the empirical results from the trial in relation to the research questions. Limitations of the work are also discussed and directions for further study outlined.

8.1 Conclusions

In chapter one five research questions were introduced and these are analysed below:

Research Question One (RQ1)

Can computer games aimed at UK Key Stage 2 children (ages 7 to 11), and designed by integrating a collaborative approach to the teaching of mathematics enhance pupils' engagement with learning mathematics and further motivate them to learn?

Research Question Two (RQ2)

Do computer based games engage and motivate digital native students better than conventional dice based games?

RQ1 includes ideas promoted in the literature that the issues with learning games that have been unsuccessful are first that they have not been designed as good games and secondly that they have not been tested appropriately. RQ2 responds to the belief that the "digital native" will need the game to be computer based in order for this to be engaging for them. It was thus necessary to ensure that the game designed was a good game. This was principally achieved by involving potential users in the game design. It was also necessary to ensure that the game play mechanism required the engagement of the children with the learning outcome and that collaboration would be encouraged. Furthermore it was necessary to adopt a non-computer based game which also was a good game that involved the use of mathematics and encouraged collaboration for use in the control study. In practice it was necessary to develop such a game and this was done using components of commercial games so that there would not be a bias in terms of the aesthetic being significantly worse for the control-group game.

Studies using a commercial computer game had helped in the design decisions for the educational computer game. Results detailed in chapter seven indicate that the computer game was highly successful in engaging children in the game play. They were also observed to collaborate both through the game and by talking to each other. This engagement and collaboration were observed to continue throughout the five week trial that was undertaken. However, results of pre- and post- testing were inconclusive when the results for the whole group were analysed statistically with the exception of mathematics engagement. This measure was statistically greater at the end of the experiment than at the beginning with the controlled experiment, but not with the computer-based game experiment. There were a number of issues when using the test results as the sole indicator of the success of the game in teaching. The first of these was that those who had perfect scores in their pre-test (or even high scores) would be unable to increase their scores as they had already shown a high level of skill in the original test. When the results were analysed on an individual basis, however, it was clear that those who could improve their performance the most had indeed done so.

Comparison with the control group indicates that in general the conventional game produced largely similar results to the computer game, with the exception of maths engagement mentioned previously. While there was some resentment expressed by the players in the control-group of not being in the experimental group their performance in pre- and post-test was not significantly worse and overall their attitudes were slightly better than those in the computer game group.

RQ1 is thus generally affirmed but RQ2 is not generally affirmed. A well designed computer game was shown to be able to engage children with collaboration in maths problem solving but it was no better in engaging the students than the dice game and indeed, the dice game was better at enhancing engagement in maths. Both could be seen to be successful in stimulating collaboration and engagement with the mathematical ideas used in the game. This is a significant finding. If Prensky (2001, 2006) is right then the conventional games will not work with the "digital natives". All of the participants had a high level of exposure to computer games and would therefore, according to Prensky, find conventional games boring and not engaging to the same extent. This was not seen once some frustrations with the dice game had been removed by including more challenge in the dice game puzzle making. A well-designed dice game was equally able to motivate and engage as the computer game, if not better.

Research Question Three (RQ3)

Are children in the Key Stage 2 age range capable of collaborating? If so how can this be encouraged in game play activity?

This research question arose partly as a result of observations of children in this age group playing a commercial entertainment game designed with significant collaboration components and in response to a number of studies that seemed to indicate that collaboration would not occur in an educational environment for this age group. The main reasons given in the literature for this relate to the nature of the competition in learning in the early years and potential unwillingness of young learners to expose their lack of understanding to their peers (Daiute1985). It was believed by the researcher that the nature of games in general would negate any of the latter effect and so the games would promote collaboration. An alternate research question was thus postulated – especially for those with lower maths skill.

Research Question Four (RQ4)

Will children with low maths ability find it difficult to engage with the gameplay or collaboration and will they therefore not engage with or learn the mathematics?

This would be because they would have less intrinsic motivation for mathematics and be more fearful of showing this in a collaborative environment.

Whether or not transferable learning had taken place was difficult to estimate for a proportion of the children as they were of high ability and performed well on the pre-test so were expected to perform well on the post-test. However, collaboration was evident with all groups and the majority of the participants. This was true both in the experimental group and the control group. RQ3 is thus affirmed. If the lower maths ability children had not engaged with either the game play or the collaboration they would show no improvement in maths score. RQ4 is therefore shown to be negative; the very children who improved the most between the pre- and post-test were those of lower ability. Detailed analysis of their performance while playing the game showed that they either engaged with the game mechanic – being willing to work on improving their answers when wrong – or they learned from listening to others and asking questions. This group had changed attitudes to their ability to learn mathematics and expressed this as comments in their feedback.

Research Question Five (RQ5)

Will the use of a mixture of game based learning with conventional learning encourage children to learn maths and maths problem solving? And how will this be indicated by improved attitudes to the subject and study?

This research question is more difficult to answer from the results of the tests and evidence from the student interviews, while positive in their comments, is not significantly matched by their questionnaire responses. However, comments from the interviews with the teachers indicate strong evidence for this research question being affirmed. Teachers reported improved enthusiasm for the subject and one indicated that attendance on experiment days was better than other days.

8.2 Lessons to be learned

RQ1, RQ3 and RQ5 have in general been affirmed and RQ2 and RQ4 not affirmed. However, due to the improvement of performance of the less able students, and the general enthusiasm for the impact of the experiment in the school concerned there are a number of important lessons to be learned. The computer game, while remaining more attractive than the conventional game for the majority of the age group, was no more effective in encouraging their participation. This would indicate a need for a variety of activities to engage even the more disaffected in the learning process rather than the computer game based solution emphasised by Prensky and others.

As was stated with the description of the testing of RQ1 a number of those with middle ability actually obtained lower scores in the post-test than they had in the pre-test. It was thus useful to look at whether these students had failed to engage with the game mechanic properly or had failed to engage with the collaboration, or both. Detailed analysis of their performance – including their game play behaviour as recorded automatically, their observed play and collaboration practices – showed this to be true. What is not evidenced necessarily is why their post-test scores also went down. It must be emphasised that the numbers involved in this experiment that had shown both large improvements in their skill level and those who had shown large reductions in their apparent skill were small compared to the numbers in the experiment as a whole and factors outside of the experimental procedure could well have been involved. It would be helpful to be able to repeat the experiment with earlier age range children as this would remove the difficulty of higher scorers not being able to improve, thus impairing the validity of overall measures of game play behaviour. Alternatively the game should be used over a more prolonged period starting when material was newly introduced to a class and thus potentially showing a greater effect for a larger number of students.

While other factors could have been in play it is believed from analysing the game play performance of those who went down significantly rather than up, or remaining constant in their post-test scores that they had engaged less well either with the game mechanic or the collaboration. The design of the game had been made so that the game mechanic had to be engaged with to make significant progress and while some players might tend to gain their answers from other players this would be another way to learn. However, by analysing the transcripts of the observations and click stream behaviour it was clear that those students who performed badly in the post-test had made a lot of use of guessing in their answers and/or had failed to engage constructively with the collaborations.

8.3 Suggestions for further work

A number of issues have been highlighted in the text. Though the final experiment took place over five weeks it was near the end of the school year. This was valuable in some ways as this is not normally a time when it is easy to engage the students in work activities but the games (both the computer game and the dice game) succeeded in stimulating interest in the maths classes at all levels. However, as suggested by one of the teachers it would be good to use the game from the beginning of term. This would enable a more longitudinal study which could examine whether the effect of games is maintained.

For a game of this nature to remain engaging for a longer period more levels would be necessary. The "stepping stones" level had been developed far enough to be usability tested and had proved engaging in that test but further work would allow this to be more properly integrated into the adventure game. Further levels would also be necessary to take the game to be used in practice in schools as a commercial product.

The levels of the current computer-based game limited the challenge posed to more able pupils. The more able pupils did not improve in this study because they were already achieving high scores on the types of mathematical problems the game presented to them. The game could be extended to incorporate more complex problem solving as well as more types of problems to offer challenge at a deeper level and over a wider range of topics. This could then more fully address RQ1 and RQ2 with respect to a range of abilities. Additionally RQ4 was not affirmed and it would be useful to consider whether the improvement in engagement in less able children would have been matched by a significant improvement in more able children if those children with higher abilities had been challenged more.

While the games were pre-adaptable for difficulty level by the teacher input interface, in order to maintain engagement for particularly more able pupils it would be necessary for the games to self-adapt during play thus improving the flow in the game by maintaining challenge that is not beyond the student's ability but is not below their ability either.

A significant finding from this study is that computer games should not entirely replace conventional teaching methods. The study was conducted in the classroom but the other teaching methods and activities were not monitored. A much more extensive study could involve observations of how the computer game-based learning would be integrated by teachers into the teaching day. This could include examining how various teaching methods could combine with the computer game and whether there is an optimal proportion of time that the computer game should be used to achieve maximum benefit.

Collaboration is key to engagement in the game mechanic. The role of competition, however, was not really investigated. This could be examined further to determine whether competition could be used to enhance collaboration and hence engagement. A computer game obviously presents an ideal platform for introducing competition but it needs to be designed carefully to keep communication open between team members. It would be interesting to investigate whether and/or how competition could be used to strengthen collaboration and whether this in turn benefits the learning through enhanced scaffolding opportunities.

Click streams were used to collect data about interactions with the game for the purposes of analysing pupil behaviour. However these data could be used to inform and adapt the game behaviour to further enhance the idea of game adaptation suggested earlier. Further to this the data could be used to trigger hints or uncover undiscovered items to make the game more engaging for lower or higher ability pupils respectively.

8.4 Summary of contribution

A number of research questions were posed in the current work. The research questions were formulated to react to beliefs about the use of educational computer games and collaboration that had been strongly stated in the literature. These wide spread beliefs needed to be challenged as they lead to the view that education without the use of computer games will not be successful with the "digital native". The findings of this study are that while computer games can be used for supporting learning of mathematics at Key Stage 2 they have to be included in a framework of learning tools rather than as the sole way of learning. Some in this age group can find it less engaging than others to use games.

Prensky (2011) has claimed that the reason educational games have not had more impact and been seen to be valuable is that they are not well designed as games or not well tested. The current study made sure that the game was designed well, was attractive to children of the target age group and that the testing was well designed. The game mechanic was designed so that children had to engage with the learning outcome but still there were children who were happy to engage with game play – even over a period of 5 weeks – but who failed to engage properly with the game mechanic.

There is a substantial amount of scholarly research that implies that collaboration encourages learning. However, there are many who feel that this does not work in the age group that was the focus of the current study.

This study has therefore contributed a number of things. Firstly, it shows that the use of both computer games and conventional games encourages this age group to collaborate. Secondly, it presents the design and implementation of two types of game which promote collaboration and engagement: a computer-based game and a conventional dice-based game. Thirdly it shows that collaboration can enhance the learning of mathematics for lower ability participants through enhancing engagement. This is an important finding because it suggests that collaborative game-play can make it easier for pupils who might otherwise feel uncomfortable with engaging with material they find difficult. Fourthly it shows that engagement and collaboration in serious games are key to enhanced learning performance; engagement does not necessarily happen without collaboration but collaboration encourages engagement. However, finally, and perhaps most importantly, it shows that an ideal learning environment in the classroom should make use of both traditional teaching methods as well as game-based (and not necessarily computer game-based) learning.

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10 APPENDICES

Appendix 1 Current Classroom Practices

Pupil Questionnaire

Children Questionnaires for key stage 2 in Southworld primary school

Please paint the answer that is most appropriate

Are you: Age Boy Girl

Do you use any computer software in maths classes?			
If you had this software at home would you use it?			
Do you like to ask your teacher when you are not sure about your solution?			
Do you look at corrections in your maths work and try them again?			
Would you like a computer game that helps you to understand maths better?			
Do you like to discuss your answers with your friends?			
Do you enjoy to work together with your friends to solve maths exercises?			
Do you like to share your answers with your friends?			
Do you think working with your friends will help you to get better at problem solving?			

Appendix 2 Current Learning Environment

Teacher Questionnaire

Teachers Questionnaires

Could you please contribute with us by giving your opinions on the children mathematical problems in order to help us finding a solution.

Class: children age:

1. What makes problem solving topics difficult for key stage 2?

   ……….

   ……….

   ……….

2. What kind of difficulties do most children have with problem solving?

   ……….

   ……….

   ……….

3. Why does there seem to be these kind of difficulties?

   ……….

   ……….

   ……….

4. What kinds of materials do you think would be beneficial for use inside or outside the classroom in order to teach problem solving?

   ………
   ……..
   ………
   ………
   ………
   ………

5. Is there any solution that you have found which helps problem solving difficulties?

   ………
   ………..
   ………
   ………...
   ………
   …………..

6. Do you think that playing different types of games will help children understand the concept of problem solving better? Why?

   ………
   …………
   ………
   …………
   ………
   …………

7. Would making problem solving topics more fun help?

   ………
   …………
   ………
   …………

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8. Do children interact with each other when using educational software in class? (in any discipline)

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9. Do children enjoy using educational software in class?

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10. Do you use a computer to teach problem solving in math? If yes could you please specify which program?

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11. How important is collaboration among children for achieving in maths?

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12. Do you think collaboration between children would help them with problem solving?

………

……………………..

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……………………..

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……………………..

Appendix 3 Teacher Responses to the Current Learning Environment Questionnaire

Teachers Questionnaires

Could you please contribute with us by giving your opinions on the children mathematical problems in order to help us finding a solution.

Class: 5 children age: 8, 9, 10

1. What makes problem solving topics difficult for key stage 2?

   The open nature of problem solving tasks and activities. Children sometimes prefer a definite end to tasks and with finding all possibilities. Children become frustrated.

2. What kind of difficulties do most children have with problem solving?

   Trying out different approaches, knowing which problems require specific methods. eg. table, trial and error, finding all possibilities

3. Why does there seem to be these kind of difficulties?

   It is challenging to recognise certain problems and their related methods. Sometimes there is no right answer

4. What kinds of materials do you think would be beneficial for use inside or outside the classroom in order to teach problem solving?

   I think it would be beneficial to have problem solving packs with equipment such as counters chess boards and straws

5. Is there any solution that you have found which helps problem solving difficulties?

   Teaching different methods of problem solving such as logic, finding all possibilities and trial and error allows children to choose their own method

6. Do you think that playing different types of games will help children understand the concept of problem solving better? Why?

I ~~play~~ think playing different types of games will engage ~~people~~ pupils in problem solving. Good teaching needs to underpin games.

7. Would making problem solving topics more fun help?

Problem solving topics can be frustrating and time consuming, making them fun would engage pupils and motivate them to complete a task.

8. Do children interact with each other when using educational software in class? (in any discipline)

Children usually work in groups or pairs so they have a partner to discuss ideas with.

9. Do children enjoy using educational software in class?

Children really enjoy using educational Software.

10. Do you use a computer to teach problem solving in math? If yes could you please specify which program?

I often use smartboard files aswell as excel files to support problem solving

11. How important is collaboration among children for achieving in maths?

Collaboration in problem solving is absolutely key. Even as adults we do not solve problems without seeking advice.

12. Do you think collaboration between children would help them with problem solving?

Collaboration between children does help them with problem solving they ask advice and approach problems in different ways.

Thanks

Appendix 4 Thematic Analysis of responses to Collaborative Game

Experiment 1

Group 1

Gender: Boys

Age: 10 + 9

Both boys considered themselves to be expert with regards to the game because they had played the Harry Potter Lego Game before, although it had been a long time ago.

The boys were really excited[e] to play the game again and because of the competition element. This was evident because they were worried about the time; **they kept asking me "how long is left?"**

The first player (10 years old) preferred to stand up[p] for the entire 25 minutes of playing. There were several children standing around watching the computer screen during game play and for the first 10 minutes of the game all of these children were excited[e] as was evident by their position close to the front of the screen.

The assistant called to them and asked them to move away from the screen because they were standing too close to the screen and preventing the other children from seeing the game. **I asked them "Why are you standing up?"** and their answer **was "We are used to standing up during playing; we feel more comfortable."**

The players were more interested in completing the level[go,co,sp] rather than collecting the coins (which was a goal of the game) because they knew that if they finished the level within a certain time they would win the competition.

The players talked with each other for the whole 25 minutes. The conversation[c] between them never stopped. **For example,** the first player said **"Smash that thing up[i]." "Why did you jump on me[q]? Do not do that[i]." "Wait, wait, go to the bridge[i]."**

The second player said "**I know there is something we need to do around here[s]; jump over here[i] and try to put these together[i,m]".**

It was evident that the collaboration among the players was very effective and helped them to finish the level quickly[s,g].

During game play children around them started to be more involved[im] and were sharing things[s] with the players without themselves thinking of the competition among them. **For example,** one of the boys who was standing around them said “There is something on the ground here, look[i,di]” and he moved closer to the screen[im] and indicated to the screen with his finger[g], pointing to the stick on the ground.

The observation of the children’s behaviour confirmed that the interaction level between the children and the game was really high.

It could be seen that this group was very competitive because they did not want to tell the other groups anything[w,cp] and once their session was finished they left the area quickly.

By the end of the game, they had collected 101,320 coins[co].

Second Experiment

Group	Gender	Age	Experience
1	Boy	10 years old	Expert
	Boy	7 years old	Non expert

Notes

Both players were excited[e] to play the game because they were talking[c] enthusiastically to each other. **However**, there were lots of interruptions. For example the second player went to the toilet during the first 5 minutes of game play and after 15 minutes of game play the first player left the game because his parents collected him.

There was not any conversation between the players. **But** the group of boys around the players show lots of collaboration[c] . They were contributed with the players by talking and helping with lots of information)

The older player asked one of the boys who was sitting around them to explain to him how to use some of the tools within the game[q]. **For example** t**he first player asked his friends "What does he need to press in order to repair the blue car?[q]"** His friends said **"You need to change characters to Wesley[i], then hold the B button[i] in order to fix the car[s]."**

The boys around the players showed lots of interaction and they were quite happy[f] to have a chance to watch and participate within the game.

Group	Gender	Age	Experience
2	Boy	9 years old	Non expert
	Boy	10 years old	Non expert

Notes

The youngest boy was curious about the game and wondering how to play it[ch].

Both **players** asked the previous group to help them[q]. **For example** one of the players asked **"When will I have new characters?"[q]** One of the boys around them answered him: **"It's like every 50 or 100 points you will have new characters.[s]"**

The players did not show any kind of collaboration between each other and they did not talk to each other. Also, the second player tried to hold[p] the first player's controller in order to help him jump but he refused[d] to give him the controller whilst not saying anything.

The second player (10 years old) showed lots of physical movement[p] during game play. For example he moved, rocking back and forth[p] while sitting on the edge of his chair[im] and he did not lean back in his seat until the level was finished.

Appendix 5 Example Game Design Criteria Player Questionnaire and Free Response answers

Third Experiment

<table>
<tr><th colspan="6">Question</th></tr>
<tr><td colspan="6">2. Is there any complexity when you play Harry Potter Game? Give an example?</td></tr>
<tr><td colspan="6">Answers & Gender</td></tr>
<tr><td colspan="2">Yes</td><td colspan="2">Not really</td><td colspan="2">No</td></tr>
<tr><td>B</td><td>G</td><td>B</td><td>G</td><td>B</td><td>G</td></tr>
<tr><td>0</td><td>2</td><td>6</td><td>7</td><td>8</td><td>7</td></tr>
<tr><td colspan="2"><u>Girls</u>

It’s difficult for me to play because it’s my first time playing this game.

I feel like if I am lost because I forget each time which button that I need to press.</td><td colspan="2"><u>Girls</u>

When you using magic regarding build things it seems to be hard a little bite.

Just in the beginning of the game it’s hard until you know what you need to do exactly.

When you try to follow the instruction regarding solving the problem so the gate can open.

Because we never play Harry Potter before so it’s hard for us.

<u>Boys</u>

The hardest thing that you do not know what you need to do next.</td><td colspan="2"><u>Girls</u>

The instructions help a lot.

If you playing with boys they will help you a lot to play.

<u>Boys</u>

Because the game has lots of hints.</td></tr>
</table>

<table>
<tr><th colspan="6">Question</th></tr>
<tr><td colspan="6">3. Is there any challenge when you play Harry Potter Game? Give an example?</td></tr>
<tr><td colspan="6">Answers & Gender</td></tr>
<tr><td colspan="2">Yes</td><td colspan="2">Not really</td><td colspan="2">No</td></tr>
<tr><td>B</td><td>G</td><td>B</td><td>G</td><td>B</td><td>G</td></tr>
<tr><td>1</td><td>4</td><td>9</td><td>10</td><td>4</td><td>2</td></tr>
<tr>
<td colspan="2"><u>Girls</u>

Because it is confusing a little bit.

It is hard to figure how to use Xbox its self.</td>
<td colspan="2"><u>Girls</u>

Because its easy so we do not have enough challenge.

There is a challenge when you try to build things.

Because when you have to get the coins its difficult to know what button that you need to press.

The challenge will be just when you fighting the ghost.

Its challenge a little bit because it is not that much hard.
<u>Boys</u>

It is challenge a little bit.

We do not know how to use the magic to build thing, and these are challenge a little bit.

Because when we work together there is no challenge.

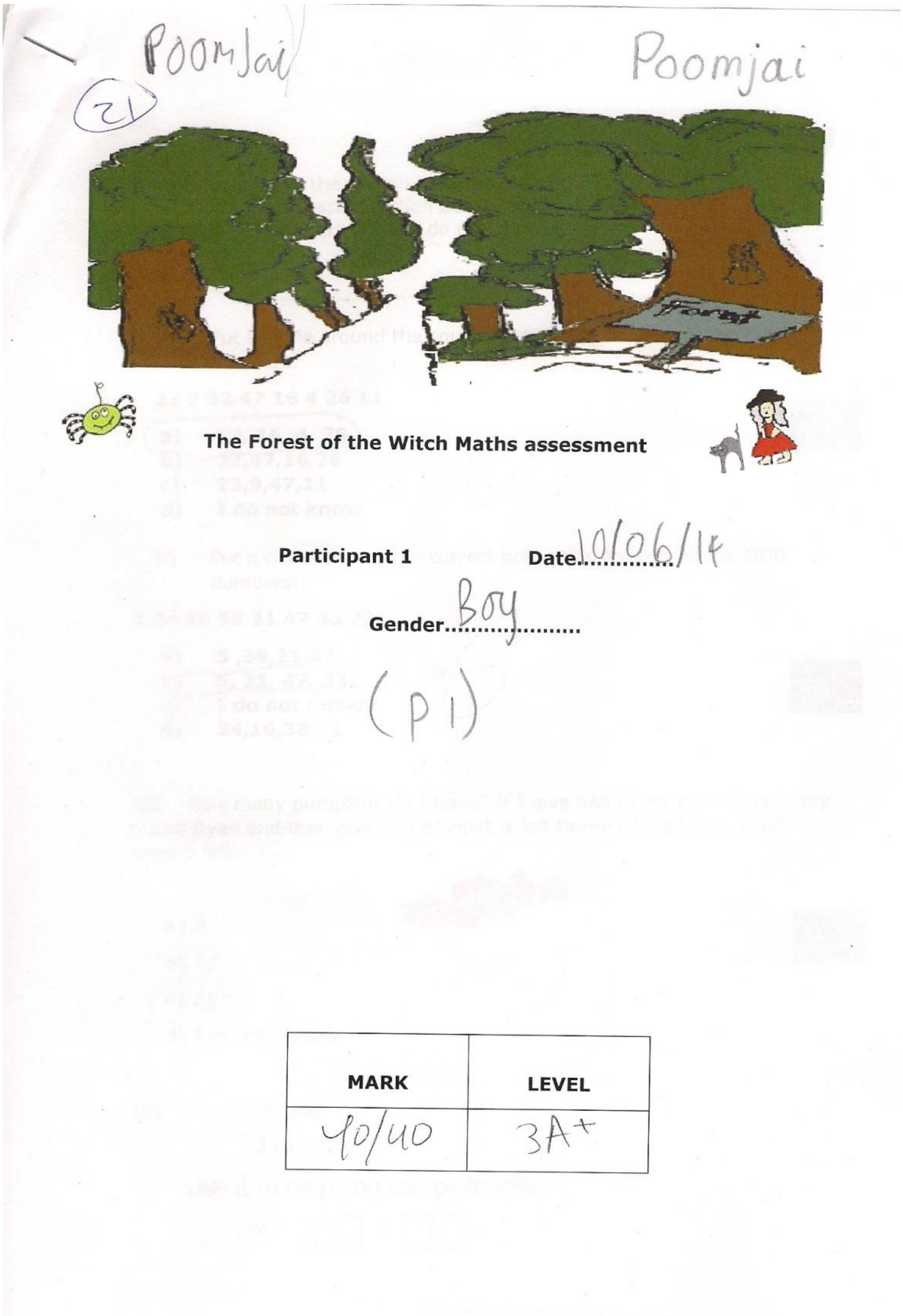
There is nothing in Harry Potter relate to challenge, while racing need you to focus more.</td>
<td colspan="2"><u>Girls</u>

In the beginning there is a challenge but when you know who to play and been in it will be so easy.

<u>Boys</u>

Because we think it is too easy.</td>
</tr>
</table>

Appendix 6 Pre and Post-Tests used in the Control Experiment



Poomjai

Poomjai

21

Forest

The Forest of the Witch Maths assessment

Participant 1 **Date**..10/06/14

Gender..Boy

(P1)

MARK	LEVEL
40/40	3A+

Hi Student,
Draw a circle around the correct answers. Try your best to answer each question but if you do not know the answers chose I do not know.

Q1

a) Put a circle around the correct group that include all the EVEN numbers:

23 9 32 47 16 4 26 11

a) 32, 16, 4, 26
b) 32,47,16,26
c) 23,9,47,11
d) I do not know

✓ 1

1

b) Put a circle around the correct group that include all the ODD numbers:

5 24 16 38 21 47 33 22

a) 5 ,38,21,47
b) 5, 21, 47, 33
c) I do not Know
d) 24,16,38,22

✓ 1

1

Q2 How many pumpkins do I have? If I give half of my pumpkins to my friend Ryan and then give half of what is left to my friend Holly, I will have 6 left.

a) 6
b) 12
c) 24
d) I do not know

✓ 3

3

Q3 You know that

12+4 = 16

Use it to help you complete this:

16 - $\boxed{12}$ = $\boxed{4}$

a) 16-12=4 and16-4= 12

b) 16-16=0 and16-12=4

c) 16-12=4 and 16-16=0

d) I do not know

3

3

Q4 Write numbers in the matching box to total 20.

13	16	14
18	15	19
10	12	17

3

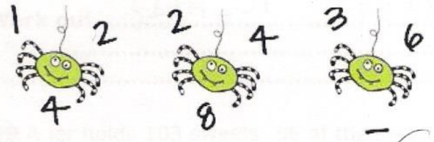
a) 7, 4, 6
2, 5, 1
10, 8, 3

b) 2,5,1
10,7,3
7,4,6

c) I do not know

3

Q5 The spiders are playing with numbers. Find the pattern and work out what the missing numbers will be.



6

6

a) 2
b) 12
c) 9
d) I do not know

Q6 Look at this number pattern. What is the next number in the sequence?

53 43 33 23 $\boxed{}$

a) 20
b) 13
c) I do not know
d) 63

4

4

Q7 Write the number that should go in the empty box.

657= 600+ $\boxed{}$ **+ 7**

a) 20
b) 50
c) 70
d) I do not know

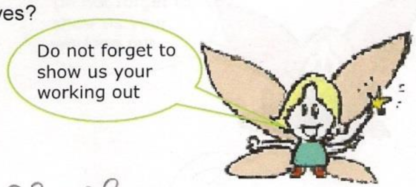
3

3

Q8 There are 19 books on the top shelf and 32 books on the bottom shelf. 23 of the books are taken away.
How many books in total are left on the shelves?

a) 43 books
b) 23 books
c) 28 books
d) I do not know

4

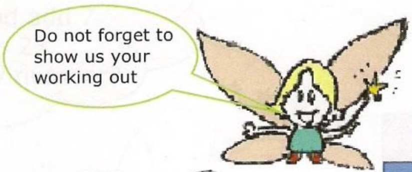


Work out 32+19=51 51-23=28

4

Q9 A jar holds 103 sweets. 98 of the sweets are eaten
How many are left?

a) 10 sweets
b) 5 sweets
c) 55 sweets
d) I do not know



Work out 103-98=5

4

4

........60 Times..

Q10 Batty loves saying "Boo!"
If he says "Boo" 6 times every minute, how many times will he says "Boo" in 10 minute?

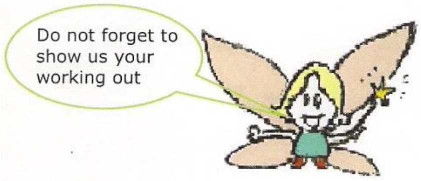
4

a)12
b) 16
c) 60
d) I do not know

a

Q11 Who am I?

Times me by 5
and subtract 7
you get 18.



a) 20
b) 32
c) 5
d) I do not know

3

Work out 18+7=25 25÷5=5 ....

....

....

3

Q12

I think of a number
I double it and add 7
The answer is 23
What was my number?

a) 8
b) 5
c) 7
d) I do not know

1

1

Appendix 7 Examples of Teacher Interview Responses to the Controlled Experiment

Teachers' Interview Questions

- Did you notice a difference in approach to mathematics in the normal classroom of those children who had been playing the computer game compared with those who had been playing the dice game?
  I haven't noticed any difference between the two groups in their abilities or approach to maths.

During the experiment, two activities were undertaken by two groups of students; the computer game group and the dice game group.

- Did you notice any difference in the classroom between these two groups in the following:
  - Motivation to solve problems
  - Willingness to contribute in class
  - Responsiveness to others' answers
  - Engagement in maths activities

- Please expand on your answers:

  There was no difference between those two groups.

- Did you notice any difference in the classroom between these groups and the children who did not take part in the experiment, in the following:
  - Motivation to solve problems √
  - Willingness to contribute in class √
  - Responsiveness to others' answers √
  - Engagement in maths activities √

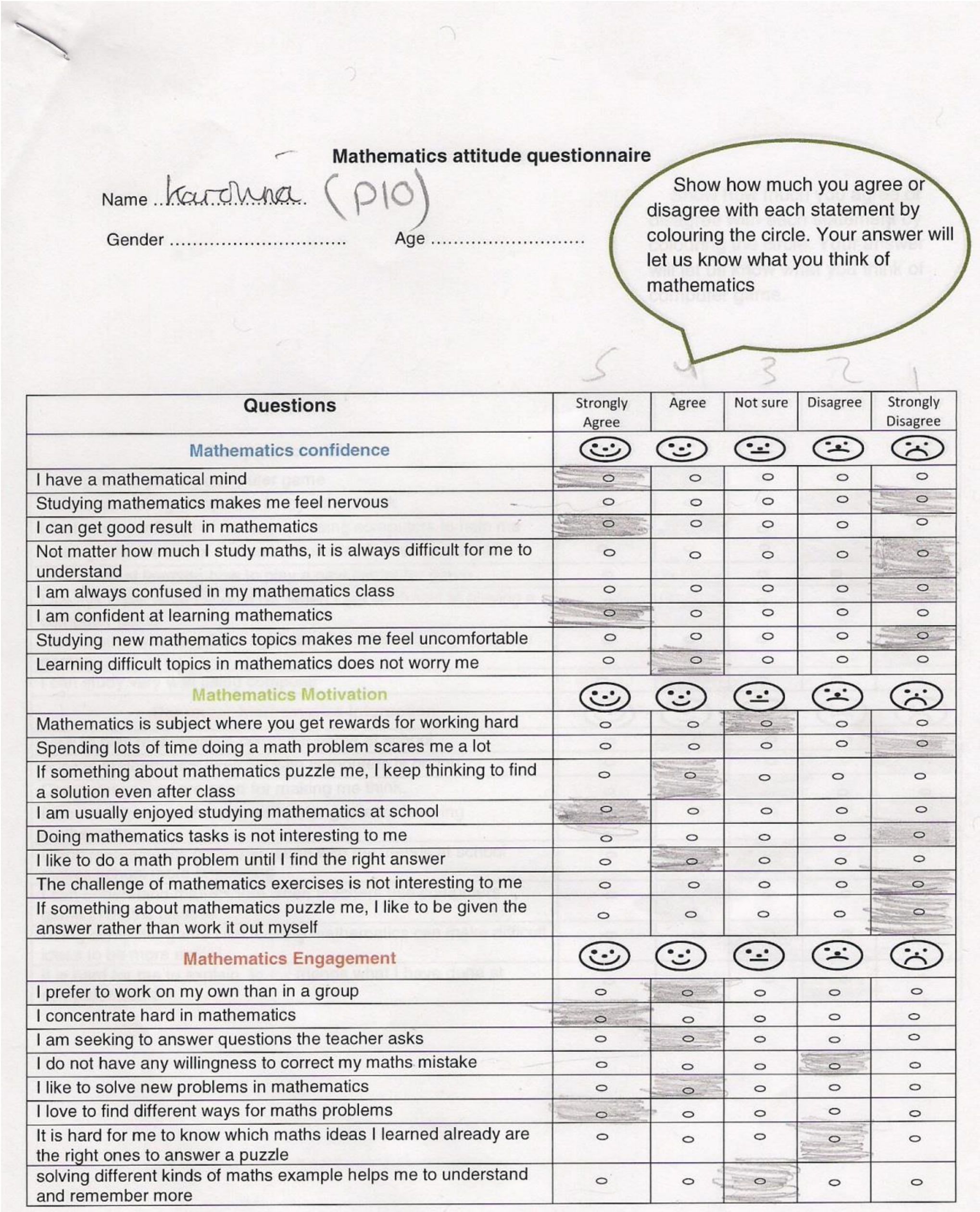
- Please expand on your answers:

All children in the class have shown increased engagement in activities. They discuss each other answers and build upon them. There is much more hands up in whole class and children are more confidence with their answers.

- Have you noticed any difference in the children's performance during the course of the study?

Children have shown more perseverance in class whereas before they would have given up.

Appendix 8 Examples of Attitude Questionnaire Responses



Mathematics attitude questionnaire

Name karchna (P10)

Gender .... Age ....

Show how much you agree or disagree with each statement by colouring the circle. Your answer will let us know what you think of mathematics

Questions	Strongly Agree (5)	Agree (4)	Not sure (3)	Disagree (2)	Strongly Disagree (1)
Mathematics confidence					
I have a mathematical mind	●	○	○	○	○
Studying mathematics makes me feel nervous	○	○	○	○	●
I can get good result in mathematics	●	○	○	○	○
Not matter how much I study maths, it is always difficult for me to understand	○	○	○	○	●
I am always confused in my mathematics class	○	○	○	○	●
I am confident at learning mathematics	●	○	○	○	○
Studying new mathematics topics makes me feel uncomfortable	○	○	○	○	●
Learning difficult topics in mathematics does not worry me	○	●	○	○	○
Mathematics Motivation					
Mathematics is subject where you get rewards for working hard	○	○	●	○	○
Spending lots of time doing a math problem scares me a lot	○	○	○	○	●
If something about mathematics puzzle me, I keep thinking to find a solution even after class	○	●	○	○	○
I am usually enjoyed studying mathematics at school	●	○	○	○	○
Doing mathematics tasks is not interesting to me	○	○	○	○	●
I like to do a math problem until I find the right answer	○	●	○	○	○
The challenge of mathematics exercises is not interesting to me	○	○	○	○	●
If something about mathematics puzzle me, I like to be given the answer rather than work it out myself	○	○	○	○	●
Mathematics Engagement					
I prefer to work on my own than in a group	○	●	○	○	○
I concentrate hard in mathematics	●	○	○	○	○
I am seeking to answer questions the teacher asks	○	●	○	○	○
I do not have any willingness to correct my maths mistake	○	○	○	●	○
I like to solve new problems in mathematics	○	●	○	○	○
I love to find different ways for maths problems	●	○	○	○	○
It is hard for me to know which maths ideas I learned already are the right ones to answer a puzzle	○	○	○	●	○
solving different kinds of maths example helps me to understand and remember more	○	○	●	○	○

Appendix 9 Examples of Observation Notes and Thematic Analysis for the Control Experiment

Group (1)

This group involved three students P7, P6 and P15. Both P7 and P6 were considered by the teacher as highly able in maths while P15 was considered as a middle-ability student.

In the beginning of the session the students asked the researcher why they did not have chance to play the computer game like the other group. The researcher explained to them that she needed different groups for each activity and they had been chosen by their teacher to do this activity.

P7 consistently showed lots of confidence during the sessions by showing off and proving that she could solve any hard maths problem. For example, P7 said “I will do this one(cf)(e)”, P7 said “I have solved it(cf)”, “Yess”(cf)(e), and P7 added “this is easy(cf)”. P7 was more interested in the dice maths game than the puzzle game in which she was focusing(cn) on solving the maths problem. Moreover, P7 showed lots of body language like singing(pm) and dancing(pm), and said “yeah, yeah(c)” which shows enjoyment(f) of the dice game. However P7 preferred to solve the maths problems by herself(ie) without any help from her team and she did not show much collaboration with others to solve the maths problems. For instance, P7 said “I will do it(cf)” “do not tell me what to do because I know how to do it(cf) (i)”.

P15 had a bored expression[(bfe)] on her face, and said “ohhh” in a way which indicated her lack of motivation to play the game. Unlike P7, P15 was more engaged with the puzzle game because she was stood up[(pm)] each time when the puzzle part of the game began and she engaged with looking[(cn)] for suitable pieces[(cn)] to complete the puzzle[(go)].

P6 was behaving quietly[(qu)], however, since she was engaged with both game activities (the dice maths game and the puzzle game). She expressed her interactions by some body movements like standing up[(pm)], dancing[(pm)] and moving quickly[(mq)] between the two games. P6 exerted lots of effort to collaborate with P7 and P15 by talking[(c)] and asking questions like "how can we find different ways to make a number? [(q)]", however; she was ignored[(ig)] by the others. This is could be due to P7 preferring to play without collaboration[(ie)] and P15 being more interested in solving the puzzle game[(go)].

The group was not able to win the first round. Therefore, for the following sessions they tried to increase the level of collaboration among them by sharing ideas[(s)] and discussion[(c)]. For example, they were working together and helping each other more. P15 said “give me this piece of puzzle quickly.” [(i)] P6 said “but we need to have another piece as well because we solve the problem in two ways.” [(c)] [(ch)] P7 said “if there is enough time we can find more ways” [(e)]. Finally, the group was not able to win the first round but when they had increased their collaboration level they were sometimes able to win based on increasing the number of ways to make a number and to quickly finish the dice game board.

Group (2)

This group involved two students, P14 and P18. Both students were considered by the teacher as middle-ability students. P18 was quieter[(qu)] than P14 who was more talkative than P18. For example, P14 said "we need to make 2 by using take away" [(i)], "what do you think?[(q)]" "The numbers on the dices are 4 ,2 and 5[(s)(ch)]". P14 added "I like it[(e)(c)]" while P18 was looking at the puzzle pieces. P14 said "I found one: 4-2=2[(go) (s)], do you think we can have different way[(q)]?" P18 said "I am not sure[(c)]".

Although, the players were collaborating[(cl)] with each other by talking[(c)], sharing knowledge[(s)] and through discussions[(c)] P14 was showing more enthusiasm[(e)] when playing than P18. For example, P14 was standing up[(pm)] and shouting[(e)] some of the time which showed her interaction with the activities. In the first couple of sessions both P14 and P18 were focusing[(cn)] more on the dice game activity because they were seen forgetting to pick puzzle pieces each time they solved a maths problem in the dice game[(cn)]. Later, the researcher reminded[(hr)] them that they needed to focus on both games at the same time but they were not able to finish the puzzle games in the first couple of sessions.

Furthermore in the final sessions they decided to change their strategy while playing the game. Thus, they still focussed on the dice game[(cn)] until they finished the dice maths board game and then they fully focussed on the puzzle game[(cn)] to be finished[(go)]. Their level of collaboration[(cl)] increased more in the final sessions because these involved lots of discussion[(c)] about “what we need to do”, and sharing knowledge[(s)] to increase the number of ways that they could make the numbers on the dice maths game and finish the puzzle game and win[(go)]. Finally, they were able to finish both games before the time elapsed even once. (1)

Appendix 10 Examples of Click Stream Data from the Control Experiment

name	date	mean selections	mean deselections	mean keypresses	mean time between selections (s)	mean turn time (s)
P32	20/06/2014	2	0	40.5	6.375	19.375
P32	26/06/2014	2.5	0	48.643	6.086	19.643
P32	03/07/2014	2.345	0.034	50.276	7.926	22.207
P32	10/07/2014	2.364	0.136	58.182	9.75	26.227
P32	15/07/2014	2.852	0.444	73.556	5.364	18.778
P39	25/06/2014	2.875	0.75	108.875	7	23
P39	02/07/2014	2.2	0	61.96	5.936	15.74
P39	16/07/2014	2.632	0.368	72.684	3.74	12.316
P24	19/06/2014	2.75	0.125	111.625	14.909	46.5
P24	25/06/2014	2.542	0	53.375	5.18	16.792
P24	02/07/2014	2.238	0	46.952	5.809	16.619
P24	09/07/2014	2.28	0.28	75.64	8.789	23.2
P24	15/07/2014	2.132	0.079	68.711	6.37	16.579
P11	25/06/2014	2.625	0.458	100.542	8.222	24.958
P11	02/07/2014	2.842	0	84.421	10.111	33.474
P11	09/07/2014	2.538	0.205	70.846	8.98	25.769
P11	15/07/2014	2.69	0.619	79.643	6.407	20.857
P29	26/06/2014	2.444	0.278	91.667	6.545	21.222
P29	03/07/2014	2.133	0.267	100.8	18.656	44.733
P29	10/07/2014	2.037	0.148	69.185	12.091	26.444
P29	15/07/2014	1.794	0.147	68.853	10.694	22.059
P27	26/06/2014	2.929	0.929	91.357	8.146	30.286
P27	03/07/2014	2.516	0.29	81.645	8.564	24.161
P27	10/07/2014	2.818	0.273	72.318	4.355	19.5
P27	15/07/2014	2.621	0.276	111.966	7.868	24.69
P9	19/06/2014	2.167	0	66	10.731	28.833
P9	25/06/2014	3.292	0.375	44.542	3.747	15.458
P9	02/07/2014	3.35	0.05	34.25	3.687	15.6
P9	09/07/2014	2.296	0.259	58.704	14.387	37.37
P9	15/07/2014	2.132	0.079	68.711	6.37	16.579
P42	25/06/2014	2.429	0.429	70.857	13.265	38.5
P42	02/07/2014	2.184	0	81.105	12.012	30.395
P42	16/07/2014	2	0.045	64.182	9.568	23.25
P43	25/06/2014	2.429	0	53.5	7.971	22
P43	02/07/2014	2.447	0	59.868	4.892	14.053
P43	09/07/2014	2.2	0.167	69.9	5.242	13.833
P43	16/07/2014	2.65	0.25	74.6	6.745	19.725
P5	19/06/2014	2.5	0.333	53.5	17.4	58.333
P5	26/06/2014	2.333	0.333	80.056	6.929	20.556
P5	03/07/2014	2.5	0.4	76.8	10.5	32.75
P5	10/07/2014	2.083	0.083	57.5	16.04	36.583
P5	16/07/2014	2.294	0	71.529	10.154	26.471
P13	19/06/2014	2.25	0.062	58.625	10.111	29.625
P13	26/06/2014	2.182	0.182	53.727	7.021	19.5
P13	03/07/2014	2.143	0.071	44.893	6.5	18.536

Appendix 11 Representative Sample of Table of Transactions for the Focus Group

	Participants No	Answers	Year	Themes
What did you think of the spider computer game?	(P8)	Good because you can do different sums(e)(1)(eh)(1).	3	EM,M
	(P11)	Amazing it can help you in maths(e)(2)(ef)(1)	3	EM,M
	(P10)	Good to improve adding and take away(eh)(2)(ef)(2).	3	EM,M
	(P32)	Tricky(eh)(3) because you have got different kinds of numbers, sometimes it's small and sometimes bigger so it's hard to up them.	4	EM,M
	(P42)	I thought that it was very good because I am ever had playing computer game like there is not much of math one but it's a kind of solving and interesting(e)(3).	5	EM,M
	(P2)	I think it's quite good(e)(4) because you had to make different sums and there is only one way around it, and you can only use four fights (chances)(eh)(4) And you have to use exactly in one fight.	3	EM,M
	(P23)	Good(e)(5) because you just have four turns to solve the problem(eh)(5).	3	EM,M
	(P3)	You can adjusts to be harder(eh)(6)	3	EG
	(P21)	Amazing(e)(6)	3	EG
	(P27)	I think it's good(e)(7) because you work through a whole game.	4	EG
	(P29)	I think it's amazing.(e)(8)	4	EG
	(P30)	I think it's good(e)(9) because you have to try your best to go to the next level.(eh)(7)	4	M
	(P31)	I think it's fantastic(e)(10) because you try a challenge(eh)(8) with	4	M