DOCTOR OF PHILOSOPHY

Further Education Students' Experiences Of Learning Mathematics Through Game Design

A Serendipitous Learning Process

Gallear, Wayne

Award date:
2024

Awarding institution:
Coventry University

Further Education Students' Experiences of Learning Mathematics Through Game Design: A Serendipitous Learning Process.

By

Wayne Gallear

PhD

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

October 2021

Certificate of Ethical Approval

Applicant:

Wayne Gallear

Project Title:

Experiences of Learning Mathematics through Games Design

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

19 October 2018

Project Reference Number:

P75349

Acknowledgements

There are a number of people without whom this thesis would not have been written, and to whom I'm highly grateful.

I would like first to thank Dr Craig Stewart who started me on this PhD journey through a serendipitous meeting at games expo at NEC Birmingham. I would also like to express my gratitude to my director of studies Dr Petros Lameras, who mentored, encouraged and guided me throughout the good and the bad times of this process. Similarly, I would like to express my gratitude to Dr Sylvester Arnab for his insight, support, and praise.

I would also like to acknowledge the support of my college and colleagues at NWSLC for allowing me to do this PhD within its curriculum area.

To my mother who always believed in me, even when I doubted and in memory of my father who would say "you can do it".

However most important without my wife I do not believe I would have ever completed this thesis.

Abstract

This thesis investigated students' experiences of learning maths through designing computer games. Further Education (FE) students in an English FE college, based in a relatively disadvantaged socio-economic demographic area, were recruited for eliciting their conceptions of learning maths via game design. An important focus of this study is with regards to the maths skills a typical student acquires and permeating how learning maths is experienced and understood within the context of games design and development. The research question that this research attempted to address is: "*What are students' experiences of learning maths through making a computer game?"* A mixed method approach was carried out for illuminating both causal effects and deeper accounts on how students experienced the phenomenon of learning maths through making a game. To this line, Randomised Control Trials (RCTs) were carried out, with a control and an experiment group, to measure the effect of game design in learning maths. To gain deeper understandings of the phenomenon, phenomenography was employed to elicit categories of description and an outcome space of the different ways students experienced learning maths through a serious game. The RCT results showed that there was an average increase in maths skills from the experimental group of 13% and the average increase in maths for the control group was 3%. This is a 10% maths increase from the experimental to control group. A t-test on the data between the pre- and post- test trials resulted in $0.003553 < 0.05$, which indicates that there was a significant difference in the score gain especially between the control and the experiment group for these assignments. The phenomenographic results showed that students experienced learning maths through game design in four qualitatively different ways, as: (1) a creative approach, (2) an experimental approach, (3) a collaborative approach, and (4) a coding approach. In conjunction to the categories of description, four dimensions of variation were discerned: (1) role of the lecturer, (2) role of game idea (3) role of maths and (4) role of technology. The contribution this study makes is that it demonstrates that games design may enhance learning of maths and in particular that it delineates the qualitatively different ways a student learns maths within the context of making a game in a serendipitous learning environment. The insights gathered from these studies can help educators, not just within FE, but also in schools or universities, to develop teaching approaches to better facilitate learning maths by using the processes,

features and strategies of games design-based learning within a serendipitous learning environment.

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1. INTRODUCTION

1.1 Overview

This thesis investigated students' experiences of learning maths through designing computer games. Further Education (FE) students in an English FE college, based in a relatively disadvantaged socio-economic demographic area, formed a sample for eliciting their conceptions of learning maths via game design. This study was undertaken on a part-time basis and was embedded within the full-time practices of a FE college lecturer. An important focus of this study is with regards to the maths skill a typical student has and looking at how doing maths is experienced and learned within the context of games design and development.

Sixteen years of being an educator in the FE sector has given the researcher a unique and personal view of FE Education in UK. The passion and energy a student will have to play a computer game within an environment that is designed to block such endeavours has been observed. This has been contrasted against a background of limited motivation to participate with college studies and more specifically the study of maths. This is reflected in a review in FE education in which Professor Wolf found that less than 50% of students obtain a GCSE grade C (or above) in English and Mathematics (Wolf 2011). The figure in schools is still 60% or less (Department of Education, 2017). It may be assumed that maths skill levels for students need to be improved in order for these students to work in industry.

Such observations lead to the following lines of inquiry: if students liked playing and developing computer games, would they also like making games with maths in them? Would they engage with maths and serendipitously develop their own maths skills as they did so? Could other students playing these games also develop maths skills, simply because they enjoyed playing the game? To elucidate further, the inspiration for this research came about as a simple research question back in 2013 at the start of this research journey. That was developed as an iterative process over the course of this study.

1.2 Background

This research was carried out by an educator delivering a computer Games Design course in a FE college. The research was embedded within this context and with the particular students doing this course. The first challenge was to develop a research plan that works within the restrictions of a full-time educator's job role. However, the advantage was that the researcher had real time access to students within a real academic environment. Challenges emerged during this research journey such as during data collection and analysis and were tackled in order to offer a rigorous and original research that would contribute to the interdisciplinary field of serious games design and learning sciences. This research is unique and arguably has the advantage that it is done internally within the context of the educational process itself by a full-time lecturer.

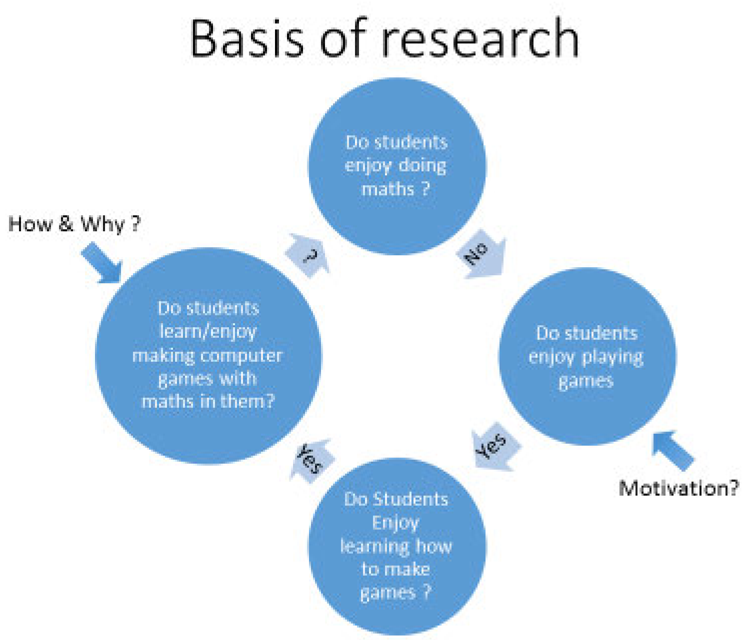

Fig 1: Basis of research – this illustrates the start of the research journey, highlighting the basis/rationale/motivation of the investigational journey.

When most of my FE students were asked, they said they did not like maths, but they did like making and playing computer games. The Games Design course had in its first year of running a large intake of eager and excitable students all wanting to make games. They were motivated to play and make a computer game. However, they were not that eager to do any maths related subject. Would a student make a game with a maths element within it? Would they enjoy that, and would they learn maths? As discussed earlier, students are struggling with maths and since 2011 the pass rate of maths is still less than 60% nationally. Maths and English training centres have been developed within large supermarkets (Sainsburys). Parents are paying for their children to use these facilities whilst they do their weekly shop. If parents were satisfied that their children were learning Maths and English at school these training faculties would not exist. A problem exists that approximately 40% of students in the UK currently fail maths GCSE (Department of Education, 2017). If students generally do not enjoy maths but do enjoy playing computer games and making computer games, why is this? One of the roles of an educator whether they are an FE lecturer or schoolteacher is to motivate students to do course work. From observation the researcher has seen the passion a typical student engages with playing computer games in the classroom even though college IT systems are specifically set up to block this process. Also, the researcher has observed the lack of motivation a typical student has for doing course work and specifically anything with a maths element within it. From this observation it can be stated that students want to play games and do not want to engage with maths (see fig 1). Also, from observation the research has witnessed the passion students engage with the Games Design and games development process. The primary focus of this thesis is looking at student experiences of maths who are doing Games Design courses within the UK FE college system. The approach, methods, and most of all the students, all reflect this education system in the UK and should be looked at within that context. However, saying that does not restrict this knowledge to only the FE education system it can be transferred to other sectors such as schools or universities and other colleges in other countries. Ultimately the multi discipline approach discussed in this thesis represents a part-time research approach taken by a FE lecturer over a 5-year period and was a journey where mistakes were made and learned from as a means to research a phenomenon which had been observed over some 18 years of teaching within this system.

1.3 Aims and objectives

The observations from figure 1 led to a research aim. A way needed to be developed to test if students could learn maths and even learn it within the context of making a computer game that has a maths element to it. This simple goal led to a simple initial hypothesis/question.

"Do students learn maths whilst making a computer game?"

However, the goal is not just about the student's learning maths. It's about understanding why they do not like maths and how to use the intrinsic motivation that they obviously have for making a computer game, to drive them to learn and possibly enjoy maths. That point of view led to looking at students' experience of making these games. Is this a good experience, or a poor one?

This then led to two research questions: -

1. Can students learn maths whilst making a computer game with a maths element within it?
2. How do students experience learning maths through making a computer game?

These two questions are referred to as RQ1 and RQ2 respectively from now on. These two questions eventually led the researcher into two parallel research studies. One with a quantitative approach and one with a qualitative approach. As this research progressed the focus gradually changed from the first research question (RQ1) to the second research question (RQ2) (discussed further).

1.4 Secondary research overview

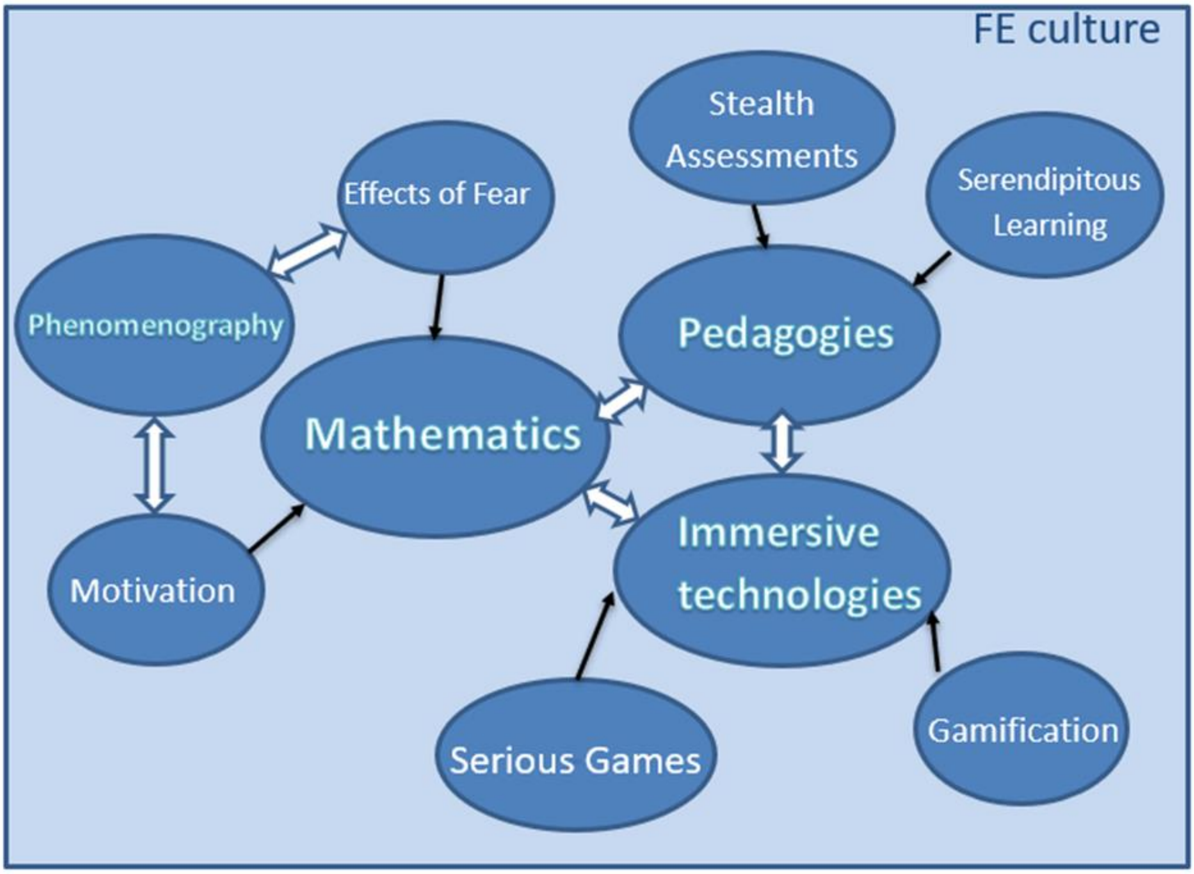

Fig 2: Overview of research themes

This thesis is organised in a way to take the reader on a journey through the process of how the research was undertaken, answering the how and why various processes took place. The three main areas were seen as maths, pedagogies, and immersive technologies. The research journey started here.

Fig 2 (above) gives an overview of how the research took place. It should be noted that the context that this research took place in was within an FE institution by a FE lecturer. Although FE and the specific culture and dynamics of this environment itself are not seen initially as a specific research area it became apparent as the research continued that the culture of FE had an impact on this study.

Chapter two: This is the FE Culture and Mathematics chapter, and it highlights the nature of FE and how the FE environment is different from schools and universities, also how this has impacted on the research. The FE process of funding is discussed and how these impacts on teaching and the student experience. Also discussed is how FE management and strategies are primarily focused on cutting costs and efficient means of delivering curriculum to an inherently underfunded education sector. How does the environment and policies and culture of FE affect the learning of maths? What is it about maths and learning maths that affects students? Why is it that some students fear it? Why do some students avoid it? How is maths within current FE courses viewed by students as a whole? Also, what effect does a student's failure in passing maths GCSE in school impact on any FE courses the student progresses onto? This links to research question 1.

Chapter three: Serious Games and Learning. This chapter starts with immersive technologies like serious games and the concept of gamification. The motivational effect of games and serious games is looked at and how this is used with education and the impact of this. How and why are they used and what is it about them that makes them immersive? The discussion moves onto learning and the different learning theories and discipline of pedagogies. The role of teachers and students within these different theories and pedagogies and what would work with serious Games Design. The concept of game-based learning is discussed and how students can learn whilst making a game. The research has particularly been done on maths learning. These core research chapters link to both research questions and is a teaching aspect of the research.

Chapter Four: Serendipitous, Incidental and Stealth teaching and learning. This is the final core research area that was done. This is research about incidental learning and serendipity and the concept of 'planned serendipity' and how that has been used. Also, a look at stealth approaches to teaching and how these are implemented within the research framework. This chapter discusses the concept of a "serendipitous learning environment" that fosters maths learning. These core research chapters link to both research questions. These first chapters give an overview of the environment in which all this takes place and the students studied.

1.5 Implementation of research

These chapters discuss how the research questions were addressed and also the initial pilot study to test the instruments of this process.

Chapter Five: The Methodology chapter discusses how experimental research took place because of the pilot study and then how it developed and progressed into two parallel studies, one that focused on the quantitative side of the research in the form of Random Control Trials (RCT) which linked with the first research question. Then a separate but a parallel qualitative, phenomenographic approach that used the same students in the RCT but linked with the second research question. It also shows how bias was observed and dealt with on this research journey and how gradually it has been reduced.

Chapter Six: The Pilot study introduces the instruments of research and tests, and experiments with using an RCT and a simple qualitative approach in preparation for the main study. The preliminary results from the pilot study (included within this chapter for completeness) and the experience learned from this process fed forward into the main study, they shaped the methodology used later.

Chapter Seven: The Results chapter elucidates the results from both approaches and shows how they link together in this mixed method approach. It shows how they have been used and how the quantitative data supports the qualitative data. RCT results from the pilot show the BIAS issues discussed above along with the main study's RCT data results. However, the focus of this chapter is the quantitively different students' experiences found through the phenomenographic process.

Chapter Eight: The Discussion chapter looks at all the results and draws out examples of the results and expands on them and what impact this has. Why did one student learn more maths than another when doing exactly the same process and with the same background? Why did a student learn to enjoy maths after initially disliking maths and why did another not like maths? The discussion chapter is about elucidating the concept of a "mind change" that is an important element in these experiments. A "mind change" is the process by which a student changes their mind about a subject, in this case maths (and/or coding). This study is compared with other similar studies. How do the results in this study compare to other comparable studies?

Chapter Nine: The Conclusion chapter summaries the finding and the implications they have. Has the hypothesis and research questions been answered? Any PhD thesis is written with the purpose of adding to the body of knowledge in a given research area. One area this research is unique in is the FE sector. Then what contribution(s) does this study bring into the research field and teaching arena? What are the limitations of this research and what could have been done better on reflection? What's next to research? What area could be researched? Also, final reflections on the research journey and what impact it has had to this researcher's life.

1.6 Published papers

It should be noted that 2 papers have been written, peer reviewed and published during this research process. Both

These conference papers are: -

Gallear, W., Lameras, P. and Stewart, C. (2019) 'Students' Experiences of Learning Mathematics Through Games Design'. In Interactive Mobile Communication, Technologies, and Learning (IMCL2019) (pp. 547-558). Springer, Cham.

Gallear, W., Lameras, P. and Stewart, C. (2014) 'Serendipitous learning & serious games: A Pilot Study'. In 2014 international conference on interactive mobile communication technologies and learning (IMCL2014) (pp. 247-251). IEEE.

The pilot study was the start of the research journey and shows how this research took place. Although this thesis goes over the research in detail, the papers demonstrate how the research developed and also some initial results that guided the analysis process. In particular, the second paper elucidated on a sample of the final data and depicted preliminary discussions linked with previous theory on how games may enhance the process of learning. It essentially provided the grounds for the data collection and research analysis to commence and be tested.

1.7 Conclusion

Maths is an important subject students need to learn, especially if the academic discipline they have followed requires extensive use and application of maths for solving certain problems related purely to maths or to computer science, engineering and in 'hard' sciences in general. Even of the students who pass maths or obtain an average grade, from research (see chapter 2) many participants dislike or have apathy to the subject (see section 2.9). The purpose of this research is to look at how students experience maths within the context of game design. The study was looking at students' experiences of a subject they do not like, embedded into a process they do like, games design.

The study was initiated with a hypothesis that students would learn maths by developing and designing a computer game. This research shows how this can work within a FE teaching context and can maybe expanded to other teaching contexts. The researcher found that there is little research on this subject in serious games or education within the FE sector. It seems that there is more research evidence on how serious games are designed and used along with their impact on teaching and learning in schools or Universities in the UK and beyond. The author hopes this research may contribute to how serious games may be used in FE in general and within the research strand of employing game design elements for learning maths.

2. FURTHER EDUCATION CULTURE AND MATHEMATICS

2.1 Further Education Culture and policies Introduction

This research and its underlying theoretical underpinnings were propagated within the context of a FE college in the UK. In summary an FE college is culturally and fundamentally different from a school. It is key therefore to bring to the fore the question: What is a FE College like?

FE Colleges provides high-quality technical and professional education and training for young people, as well as adults. FE colleges prepare students with valuable skills for the workplace, helping to develop their career opportunities. In 2015 there were more young adults in FE College than in university: 2.9 million compared with 2.4 million (Finamore, 2019).

According to Finamore (2019) a FE college helps students to develop skills for the workplace, also there are more students attending FE colleges than universities because students have the opportunity to gain foundational knowledge, technical competencies and upskilling before entering university if they wish to or entering the world of work directly (Finamore, 2019). Colleges help students finishing school gain valuable skills needed for employment in the UK. FE colleges are a fundamental sector in the education for the UK. This chapter starts with an overview of the challenges and issues there are in engaging with research within the FE environment and the affect the FE culture has particularly when compared to culture within schools. Starting with looking at the impact funding has on FE education compared to other education sectors. Then research was undertaken within this education arena, comparing it to all the various education sectors.

2.2 Nature of research in FE and HE and Schools

The next area of research is asking what research has already been done in this field in FE. One of the few papers just on UK based FE education only was written by Scaife (2004) "The Culture of the Now: barriers to research in FE". Scaife in this paper looks at problems with research in the FE sector of education in this country. Scaife argues that there are "significant barriers to sustained, well-grounded research in FE.". Scaife (2004) then criticises FE management treatment of employees against the FE "institutional dimension" (Scaife 2004) in which colleges are in a constant financial battle to gain funding. Scaife (2004) argues FE Colleges Undergoing a seemly endless 'tred-mill' of OFSTED inspections and internal restructures and/or mergers with other colleges. This financial battle puts the focus on the 'now' not on future events. In other words, the focus is to react to problems rather than be proactive to future ones (Scaife 2014). From personal observation the college this researcher/lecturer is employed by recently merged with another college now forming NWSLC from two separate colleges SLC and NWHC. This paper highlights all the internal and external issues that have been personally observed and form a backdrop to this research. Scaife also argues that college managers have an 'IKEA factor approach' to activities, to package up activities in the college to meet standardised entities which are unpacked and used when needed. Needless to say, treating staff and students as entities which can be shuffled around to meet the requirements of an IKEA factor system can be very emotionally unsettling for the parties involved. "..there seems to be systems whereby individuals can be steadily marginalised and removed should they appear to challenge dominant ways of control" Scaife goes into more detail about how FE colleges do not treat staff as the most valuable asset they have (Scaife 2014). The paper concludes that "further education is dominated by a culture of the now" (Scaife 2014). Compare this to research in an HE environment. There is a plethora of papers available of research undertaking in the HE sector. HE lecturers are encouraged and also in some cases contractually obligated to undertake research. The cohort that colleges generally attract are students who fail at school and did not necessary get good GCSE grades at schools.

2.3 Nature of Students

The nature of students does change throughout their academic lifetime. Students are initially only in compulsory education. Students in schools do certain subjects, such as maths, English language, science. When they get close to doing their GCSE they can choose certain areas, but this is limited. However, when a student has completed their GCSE's, they then get to progress to FE education. The student then has a choice of what subject they wish to pursue. Whereas the student was forced to do Maths, English, and Sciences. They can now pick one area they wish to specialise in. Which gives them a greater focus in their study. The same can be said of university students, who pick a course of study. Students are in compulsory education until the age of 19 so both schools and FE institutes are both compulsory, however the FE course is the student's choice. University is optional; however, many students see the benefit of progress with their studies and progress on to a university course. According to 2018 UCAS statistics In England, a 27.9 per cent of the 18-year-old population have been accepted onto a HE courses at a HE provider.

Galindo-Rueda et al (2004) write about this subject in their paper "The Widening Socio-economic Gap in UK Higher Education" (Galindo-Rueda et al 2004). Galindo-Rueda et al discusses how in HE enrolment, with the introduction of the student loan system, students who are in FE environment often have their eyes set on there HE future, and this has had significant impact on them, however it hasn't stopped them applying for HE courses. Galindo-Rueda et al shows that the introduction of the student loans has not impacted significantly on the participation of students going to university. Although the evidence has shown a slight increase in the students participating in university study.

However, on a positive note the authors also show that more students are wanting to go to university than ever before.

"Children from all socio-economic backgrounds are considerably more likely to go to university in 2001, as compared to 1994. In fact, the growth in HE participation amongst poorer students has been remarkably high, mainly because they were starting from such a low base." (Galindo-Rueda et al 2004).

Galindo-Rueda et al discusses the widening gap between students from richer socio-economic backgrounds compared to poorer socio-economic background attending university.

2.3.1 Student's role in schools and FE

The behaviour and expectation students have in schools is very different to a FE college. An article explains that schools are "focused on the education of minors and as such have a more prescriptive atmosphere in which students often have to wear a uniform and are not permitted to leave the school site during the school day." (Sheffield University 2021). This culture changes when the student enters a FE college. The online article explains "In contrast, FE colleges offer a more relaxed environment in which students are encouraged to take more responsibility for their education. FE students choose their own study programme and are only expected to be on campus during class times." (Sheffield University 2021). This change of culture from the school to the FE college has an impact on the students. They move from a restricted environment with rules and statutory educational to one where they choose the course they want to do. "The main difference between high school and college in the UK is that one is part of the statutory education system, and the other is part of the optional further education (FE) system." (Sheffield University 2021)

Students do not need to be in college when courses are not been run, they often turn up just for the sessions they need to do. FE College do provide extracurricular activities such as clubs and social events, these however are optional. This extra freedom the students have in FE colleges however impacts on the research that is planned. Students are also given more respect and value; students have to transition from a school culture to a college culture. DeWitz, Woolsey and Walsh (2009) argue that students who want to "become successful in college, students must learn how to manage their independence" (DeWitz, Woolsey, and Walsh, 2009.). They then add that it's not an easy transition for some students (DeWitz, Woolsey, and Walsh, 2009: 21). This "independence" is not an easy transition for some students and how they adapt to this affect them in the classroom and how they can learn (see next chapters). Also, DeWitz, Woolsey and Walsh (2009) add that "A college student can feel a fit with the institution, a fit with peers, feel supported by faculty and by students, but without a purpose or goals, the student may lack a clear sense of personal meaning." (DeWitz, Woolsey, and Walsh, 2009). The deeper philosophical nature of this concept is beyond the scope of this thesis; however, it is important to realise that a student is affected by this new college environment and how they transition to this new environment will impact on their academic achievement. The teacher / lecturer needs to be aware of this and support the "whole" student and not just focus on academic achievements. (See humanistic theory in next chapter).

2.4 Culture and policies within UK FE education

As discussed in this chapter the doing research within the FE sector has many challenges to overcome. Funding is limited within the FE sector and this impacts on a lecturer doing research and funding to implement the research itself with this environment. The research was embedded with the role of a full time FE lecturer role. As a result, a creatively embedding of the research had to take place, within this context. With the teaching of Games Design and find time outside class time to effectively implement it. FE lecturers are not given any formal time to do any research. Also, the value of research is not seen recognised within the management of FE organisations, but it is with universities and schools, so this has been a significant barrier in itself to overcome. Then the student is impacted by the transition to a FE college. They have more freedom then in school and how they transition (or not) does have an impact on them.

2.5 Mathematics research in education.

This thesis' research questions are both related to maths. RQ1 is about *whether* maths can be learned whilst making a computer game and RQ2 is about the *experiences* a student has of learning maths though a games design process.

A student will have done more than ten years of maths education prior to coming to a college course. For example, a typical student aged 18 years will have been doing maths since aged approx. 7 years old at primary school. The way they experienced maths prior to college will have an impact on how they experience it within a college environment. So, it is prudent to look at maths education within a school environment first.

In schools, according to Noss and Hoyle's research, the treatment of maths has tended to be fragmented, with one maths concept taught in isolation to others (ref? : page 16). The result being, that when a student was tested, it only gave a partial picture of a student's maths competency. Also, Noss and Hoyle argued that many learners constructed their own approaches to learning maths. According to the Department of Education and Skills and the National Council for Curriculum and Assessment, when schools focus primarily upon results rather than the understanding of maths, it tends to have a negative effect on how students use maths in later life (Jeffe et al 2013:14). This result-oriented approach to teaching maths is similar and closely related to the previously discussed Scaife (2004) 'culture of now' approach used in many FE colleges. This is a culture where the goal of education is to focus on results rather than learning. In Jeffe et al (2013) he argues that "teaching strategies based on deepening and enriching students' mathematical understanding can have a positive impact on achievement". It can be argued then that attempts of schools or colleges to focus on students getting good GCSE results (grades) have had a negative impact on the learning of maths. What is the answer? What steps can be made to enhance maths learning? Noss and Hoyle(ref) argued that learners construct their own approaches to learning maths. The Advisory Committee on Mathematics Education (ACME) in the UK has shown that teaching strategies based on deepening and enriching students' maths understanding can have a positive impact on achievement (ACME, 2011).

The 'Weblabs' project research stems from this and joins with a growing research trend in education to do with putting maths knowledge into a practical use (ref). This research also discusses creating an environment in "which learners can actively work on a conceptual level" (ref). The Weblab project used a form of animated programming called 'ToonTalk'(Mor, Y. , Sendova, E. 2022) which looks similar to a computer game. This research was done at junior schools in Bulgaria and the UK. The relevance of this is that this thesis is based on a similar premiss of *applying maths* rather than learning the *theory of maths* in an abstract unconnected way. It should be noted that the 'Weblab' project took place in schools not colleges. The difference is that it was to a younger more impressionable audience, using basic non-GCSE based maths. The students for this thesis's research generally use more advanced GCSE based maths. The researchers of the 'Weblabs' project argued that the effect that this has on those students is that they see maths within a practical construct not a standalone theoretical concept, which is how it has been traditionally taught (Mor, Y., Sendova, E. 2022) see chapter 3 and next section).

2.6 Further Education and Mathematics

The next aspect is maths within the UK college FE environment. The 2011 Wolfe report discusses the problem of students getting poor Maths and English grades at school and FE colleges.

English and Maths GCSE (at grades A*-C) are fundamental to young people's employment and education prospects. Yet less than 50% of students have both at the end of Key Stage 4 (age 15/16). (Wolf 2011)

The figure in schools is still 60% or less (Department of Education, 2018). It can be seen maths skill levels for students needs to be improved. Wolfe discusses the poor maths and English results of the English educational system and discusses in this paper how this is creating a barrier to students developing further skills. If a student fails to get a GCSE Mathematic grade 4 it can affect them when doing further study. This is particularly relevant for student when attending college, as they have to redo their GCSE maths subjects and eventually retake these exams.

In addition to this maths is part of the science, technology, engineering, and maths (STEM) UK government educational policy agenda (House of Commons 2018). According to this UK government white paper, "The future workforce relies on many more children and young people being encouraged to take STEM subjects and enter STEM careers." (House of Commons 2018).

This is against a backdrop in which traditional STEM based skills were removed from City and Guilds based format course (City and guilds was a core part of most FE college courses). The result is that when students enter a FE college environment many have poor maths skills.

2.7 Global market pressures

With globalisation and the national industries in one country competing against countries industries has led to an educational arms race.

> …investment in China alone grew from US$7 million in 1994 to US$500 million in 2000. Chinese investment in R&D doubled between 1996 and 2002. Together, China and India each produce over 2 million university graduates per year, compared to around 250,000 in the UK. Against this background, established economies such as the UK need to adapt in order to continue to attract and retain high-value economic activities. Science and innovation are at the heart of these transformations, not only because technology is itself a key driver of globalisation, but also because countries will increasingly derive their competitive edge from the speed with which they are able to innovate. (HMSO 2006)

From this It can be seen that science and maths skills are of global interest. The UK education market is in a global market that is getting increasingly more competitive. The UK economy needs better qualified students to attract 'high-value economic activities' (HMSO 2006). STEM and now STEAM are core subjects such as science, technology, engineering, arts and maths that a student needs to have to be competitive in the global jobs market. As can be seen the increasingly competitive global market is forcing developed counties like the UK to develop strategies to keep a competitive edge. One aspect of this is to get a student body with a high STEM qualification. Going on from this a source of concern for the government is the low percentage i.e. 49% (Wolf 2011) of students gaining English and Maths GCSE grade C in the UK.

2.8 Fear of mathematics

Following on from this there is an expectation for student to achieve a specific skill level in STEM qualification. Looking at maths levels students achieve. Research done by Pouyamanesh and Firoozeh (2013) discuss students, difficulties in learning maths. This reflects in the poor performance students have in achieving a significant maths grade at school and college. Pouyamanesh and Firoozeh (2013) test the students' tolerance levels of doing pictorial maths tasks. Some of the maths-based pictures were easy to do and some were impossible to complete. The task tests the perseverance of the students to attempt and reattempt the task. It's an interesting concept as it takes the students away from a traditional maths test idea, which is what some of the students have problems with anyway. This is a concept this researcher was keen to investigate. They also connect fear of failure with students re attempting Maths exams. "Students, who believe that their previous failures were because of their disabilities in school assignments learning, probably don't expect to be successful in same assignments, so unlikely they will try more." (Pouyamanesh and Firoozeh 2013)

> "Students, who believe that their previous failures were because of their disabilities in school assignments learning, probably don't expect to be successful in same assignments, so unlikely they will try more."
> (Pouyamanesh and Firoozeh 2013).

Looking at research papers in this field, some students have been observed as disliking maths. Maths is part of what is taught within every unit in a typical FE college course. Helping students overcome their distaste of maths is the goal of every FE lecturer and reading these papers show that it is a universal problem that has been encountered throughout education. Pouyamanesh and Firoozeh (2013) is not the only researcher who connects fear and maths. Putwaina and Symes (2011) discuss a method of measuring "a period of intense worry and apprehension prior to examinations" (Putwaina and Symes 2011). They show that "consequences of failure were positively associated with performance-avoidance" (Putwaina and Symes 2011). In addition, Geary (2013) argues that "innumeracy is more common" (Geary 2013) than illiteracy and many adults are "functionally innumerate when they leave school" (Geary 2013).

2.9 Mathematics apathy and poverty

Maths is traditionally taught as a standalone subject in schools with students been taught the theory of maths with varying attempts to add practical elements. As shown above if 50% in 2011 and 40% now are still not achieving maths grade 4 doesn't this indicate a failure in current educational practices?

Kislenko (2007) argues that students know maths is important but are "bored in the maths lessons" (Kislenko et al 2007). Trying to get student motivated to do maths for some students is challenge especially when according to research done by Kislenko research 54% (Kislenko et al 2007) of students find maths boring.

Taggart et al (2015) find that challenges facing students in disadvantaged communities show up as differences in the quality of their school experiences. It can be argued from this that a potential reason that a child may have poorer maths skills (which translates to GCSE grades) could be poverty related. A poor environment at school or home could shape what GCSE grades a student achieves. This is particularly relevant as the college that this study took place in is in a poor social demographic area. Taggart et al (2015) argues that the parent's qualifications and background also have an impact on the student's grades. This implies that the poorer a parent's academic grades are then the poorer the child's academic achievement is. Other factors can be parents going through a divorce; or a student may have emotional concerns at home. All these can impact on a child and their academic achievement in school. The author believes these factors and more can affect the learning and development of students including their maths skills development.

Geary (2013) did some research on innumeracy; he starts by showing that innumeracy (22%) is more common than illiteracy (14%). He looks at research about how these difficulties in maths start before children even enter school. Geary (2013) argues that "innumeracy is more common" than illiteracy and many adults are "functionally innumerate when they leave school" (Geary 2013). All these authors agree that maths learning can be impacted by many factors outside a child's / students control and that it is a common issue.

2:10 Summary

This research is looking at students (or "learners") who are doing a games design course within a FE college, not a school or University. It's also from the point of view of a lecturer who is also a researcher within this environment. Not an independent researcher looking at a FE college from an external perspective.

The first theme is the FE college's environment compared to schools or universities. One of the first areas that impacts this research and impacts the students is the culture and policies of a FE College. Scaife argues that there are "significant barriers to sustained, well-grounded research in FE.". This thesis' research took place within a FE college by a FE college lecturer to FE college students. It can be seen that doing research within such an environment is more restrictive for an internal member of staff than an external researcher. The research took place within the games design course. Ways had to be found to do this in an effective way that didn't impact on the teaching of the course or how the students or the FE management viewed the course.

The next theme is the students themselves. These students entering the FE college environment have come from a school environment. As discussed earlier, students move from an institution with rigid rules (they usually have to attend school every day at specific times) and with limited options on the education they are receiving, (a set of GCSE's) to an environment where a student has a more flexible timetable and a choice of the course that they want to do. This new independence is a skill a student needs to manage. DeWitz, Woolsey and Walsh (2009) argue this is a skill that some students struggle with.

Wolfe (2011) states maths is a very important skill for students to develop and impacts on employment prospects and educational development. Students are put under more and more pressure in schools and colleges to get to a certain maths skill level. Some students respond well to this external pressure (whilst others crumble. This external pressure comes in the form of extrinsic motivation from parents, teachers, and society as a whole. Against a backdrop of fear/apathy towards maths. Putwaina and Symes (2011) calls this "a period of intense worry and apprehension prior to examinations" (Putwaina and Symes 2011). Finding ways of supporting students to overcome their fear of failure apathy is a core area of this research. This thesis' research is for these students who struggle with maths for whatever reason.

2:11 Conclusion

As students enter the FE college environment, they transition to a less rigid educational institution with more freedom and more choices. This thesis' research is embedded within the game design course itself to facilitate some student's attitudes to maths, such as fear or even apathy.

Students *learning* maths and *how* students experience learning maths is an important part of this thesis. Students do not turn up at a FE college with no background of doing maths before. They attend schools and do formal maths sessions as part of a GCSE curriculum. Some of these students then join a FE college and undertake a computer games design course. A discussion comparing maths in schools and colleges is needed. Taggart et al (2015) discusses how the social demographic area the school (and college) is within can affect a student's maths skill.

Jeffes et al (2013) argues that students who are taught in a school whose focus is on results not learning can lead to what Pouyamanesh and Firoozeh (2013) and Putwaina and Symes (2011) describe as having a fear of failure in reattempting maths assessments. One of the challenges of this research was to evaluate methods to engage students with maths in way that facilities maths learning without students struggling with 'fear of failure'. This theoretical thread is part of this entire thesis and is continued in the following chapters.

3. SERIOUS GAMES TECHNOLOGIES AND LEARNING

3.1 Introduction

This research commenced from a personal belief and through 18 years of personal observations that 'making and playing games can help develop maths skills and give a change in attitude towards math as a whole. However, moving from a 'personal belief and observation' to academic research to prove this requires research and experimentation.

The previous chapter was more of a background to some of the FE college issues and the culture in which this research took place in order to set the context specifically of maths and how it is generally viewed by students and the culture in which this research took place and how that impacted. This research study is about how students experience and learn maths whilst designing a game and how these pedagogies link with this process. Also, why some ways of teaching would not be as effective to student's learning as some others and why some approaches were ultimately chosen to inform the learning of maths via making a game. To recap, the question that the study aims to shed light on are: "Does a student's maths ability improve with developing (and play testing) games with maths embedded in them?" Can learning take place when a student makes a game with a mathematical element within it? How does this learning take place? Finding what other researchers have written about in this theme is important within this context being researched.

The students in this research were enrolled on games design courses in an FE college. When a teacher or lecturer teaches a class, they choose and sometimes adapt a pedagogy. A pedagogy is a teaching strategy or approach that is used to deliver contents to a group of students. It is the goal of all teachers and educator to enhance the student learning experience. Understanding the various type of pedagogies and how they support teaching maths using Games Design is seen as a key component to teaching a class. This chapter explores the field of gamification, serious games, and serious games for maths as well as pedagogical approaches to teaching and learning via making serious games. This evaluation of the various approaches shows the rationale behind the eventual approach taken in this thesis.

3.2 Gamification

Gamification is the process of using a 'game' as a vehicle to deliver skills and/or knowledge to a student on a course.
Amory's et al (2019) research on the use of computer games as an educational tool provided insights on how understanding the relationship between educational needs and game elements will allow us to develop educational games that include visualisation and problem-solving skills. Amory takes cutting edge games and looks at their educational value. "Visualisation and problem-solving skills are an integral part of adventure and strategy games." (Amory et al 1999). The educational aspect is that a wide spectrum of skills is developed whilst playing the games.

Barata shows the benefits of the Gamification of an engineering course and how this was done. Students were given experience points (XP) for participation in the course material. If the students downloaded material from Moodle, they were given XP, if they wrote a post on Moodle, they were given XP etc. As they gained XP they progressed through levels, for instance level 1 was labelled "Starting to see the light", level 4 "Taking your first Steps", level 12 "Knowledge Pilgrim" and level 20 "Science God." (Barata et al 2013). Each student was shown on a leader board, and they were encouraged to compete against each other for XP.

This paper is useful in understanding the concept of Gamification and engagement which discussed the underpinning intrinsic motivational effect of 'games' which this research is utilising.

A journal was written by Renwick in an after-school computer club he ran where students played the popular computer game 'Minecraft' for one hour. He states that students immersed in games like Minecraft will persist with the challenges provided because they have a purpose, but also because they believe that their goal is attainable" (Renwick 2014). Renwick (2014) argues that games like Minecraft build up student's confidence in overcoming challenges they face in life. It's a game that equips students with essential life skills they can use outside the game (Renwick 2014).

Another paper that discusses Minecraft and the connection between playing games and learning is Cipollone et al (2014) "Minecraft as a Creative Tool: A Case Study" (Cipollini et al. 2014). Cipollone discusses "Learning approaches, such as using Minecraft, which encourage students' creativity and understanding of concepts" (Cipollone et al. 2014). A great deal of their research revolved around how the learning take place whilst playing Minecraft was "From a learning sciences perspective, the type of knowledge production that is encouraged by Minecraft can be seen as a constructionist epistemology." (Cipollone et al. 2014).

Cipollone et al (2014) research further argues that learning is taking place whilst playing Minecraft game and that this encourages creativity. It can be argued that playing serious games can encourage and support learning in a meaningful way.

> "Gamification is defined as the use of game attributes, as defined by the Bedwell taxonomy, outside the context of a game with the purpose of affecting learning-related behaviours or attitudes. This is contrasted with a serious games approach in which manipulation of game attributes is typically intended to affect learning without this type of behavioural mediator/moderator." (Landers 2014)

3.3 Serious Games

Landers argues that gameification is using game-based attributes to affect learning outside the context of a game. Then the question is what is a serious game?

The key difference is gamification uses game attributes in a non-gaming environment to affect behaviour and serious games are games with purpose to affect learning. A good real-world example of this within popular culture is the popular language learning app "Duolingo". This app has made learning a foreign language easier by making it into a game, where player get points and can progress in different leagues and even compete with friends and family. According to a team of independent researchers showed that using Duolingo increased the language abilities and was 'statically significant' (Vesselinov and Grego 2012).

According to Djaouti et al. (2015) "Serious Game designers use people's interest in video games to capture their attention for a variety of purposes that go beyond pure entertainment." (Djaouti, Alvarez and Jessel 2015). Another term for serious games is educational games. Serious games are games that have a purpose. One of these purposes could be to teach in the form of an educational game. Backlund and Hendrix (2013) conducted research in educational games to see if they had any use.

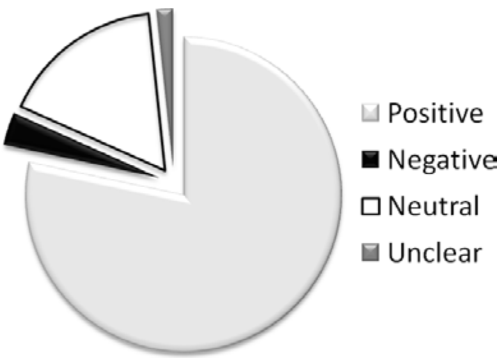

Fig. 3 Analysis of papers showing positive view of effectiveness of educational games taken from (Backlund and Hendrix 2013).

Backlund and Hendrix (2013) in their paper "Educational Games - Are They worth the Effort? A Literature Survey of the Effectiveness of Serious Games" showed that use of computer gaming in education is positive 29 out 40 papers sampled showed that they were worth the effort (shown as positive in Fig 3). The results showed serious games are of value.

One consideration for this research was whether it is necessary to always use just a pure Games Design engine such as Unity or GameMaker? Or use a game itself and its in built in features such as creating a new level.

Robertson and Howells (2008) in their paper "Computer game design: Opportunities for successful learning" (Robertson and Howells 2008) did not use a proprietary Games Design system like GameMaker, they chose an actual game and used an add-on for the game. The game they chose is the role-playing game (RPG) based adventure Neverwinter Nights software by BioWare. Robertson and Howells (2008) show that the reasons behind this are "it was suitable for use by non-expert designers without requiring computer programming" (Robertson and Howells 2008). Robertson and Howells (2008) further discuss how the add-on, which is a toolset "enables novice users to create landscapes, customise characters, write interactive dialogue and script sequences of actions."

They argue that this was called a game design and was ideal for 10-year-old learners at school. The learners can quickly and simply make changes to the game and test them. The learners that this study uses are much older and have a much higher skill set but it is still relevant. So, what are the learners learning in Robertson and Howells study? The first skill was troubleshooting. The learners make a change and then find they have problems, and the game is unplayable. For example, Robertson and Howells discuss that a student when using the game modification and testing it, finds that a "player character is finding it hard to move" (Robertson and Howells 2008). The learner after discussion with the teacher must make additional changes to fix the problem.

Robertson and Howells (2008) show that these learners are developing social skills, in particularly communication skills. This happens serendipitously in the game testing process. For example, Robertson and Howells discuss an incident with a female learner testing another game who says that "She is upset because she keeps getting killed by spiders" (Robertson and Howells 2008). This then leads to a discussion about whether the game is too hard. This all leads to a class discussion where they talk about this issue more. Some of the children like games with lots of fighting, while others prefer not to be attacked. Some of the class then decided to reduce the number of monsters in their game. In summary his study highlighted those students can learn through a process of “trial and error” and the frustration some students experienced during this process. This study was done in a limited time frame and within a school context and with 10-year-old learners. The research students with the context of my research are on a game design course itself and are 18 years old. The expectations are that they make a game not game modification as with Robertson and Howells study.

3.4 Serious Games with Mathematics research

This research focused on embedding maths within a game, so looking at previous research in this area was important as this could help with the research process. Ke (2014) wrote a paper called “An implementation of design-based learning through creating educational computer games: A case study on maths learning during design and computing” (Ke 2014).

In this paper Ke discusses the concept of “design-based learning” where students learn as they design the game using software called 'scratch'. One of the pedagogies used in this research is 'problem-based learning' which has a lot in common with 'design-based learning'. Ke (2014) also discusses in this paper how computer games can be a “powerful learning environment” (Ke 2014).

Ke (2014) states “As students design a math game, they will need to explore and represent their understanding of a math concept or interpretation of a math problem via scenarios and objects in the game world.” (Ke 2014) This is exactly what the students in this study are doing. Ke (2014) study did not use phenomenography (see the methodology chapter) however and was aimed at school children. Also, no maths was tested it was just students’ reflections on maths. So, it hard to compare from that point of view if students learned maths. However, some interesting information can be gleaned that is relevant to this study. In Ke’s study 52% of participants reported they learned maths.

One of the goals of this study is to evaluate whether the mathematical ability of students is increasing in a Games Design process where a maths element is embedded within the game that is being designed. The similarities between this study and Ke's paper are that maths is embedded in both experiments and that maths development is being measured. However, this is where the similarities stop. The students in this research are older (18+ versus the 14- to 16-year-old students for Ke's study) and the game design process is slightly different as well (Scratch system versus GameMaker engine). The assessment process of the maths development is very different, which was hidden from the student in this research. In Ke's study the students where more aware of the maths elements and were assessed on that directly.

"During post-program interviewing, more than 52% of participants reported that they learned math" (Ke 2014). Ke pilot study used a mixed method approach based on an electronic test that measures maths ability and through interviews.

Ke's (2014) research argues that students learned maths and used a mixed method approach. Also, more importantly the learners reported a better attitude toward maths. This research was seen as a very relevant paper in this thesis, as it covers some of the same themes of research.

There is a more recent publication from 2021 which looks at experiences of teachers engaged in *Inquiry-Based Learning (IBL). Using a serious game called Simaula. However, the candidates are teachers not students. This publication* by Lameras et al (2021) uses phenomenography to investigate the teacher's perspective of inquiry-based learning through serious games within the US schools' system. There are some parallels to this study. One, discussed later in this chapter, shows that IBL is related to DBL. The use of phenomenography and the educational environment is comparable to the study done in this thesis. The authors argue that IBL can help "enable deep and meaningful learning" for Games Designers (Lameras, P., Arnab, S., de Freitas, S. 2021). One difference is that Lameras et al (2021) was specifically focused on the teacher perspective of inquiry-based learning (IBL), which is different from this thesis' study which was on the students' experiences of maths. The researchers argue that learning takes place, without an additional quantitative process.

3.5 Students experiences of learning through making games

Another aspect of this research is looking at student's experience when making a game with maths element within it. How does a student experience maths when making a game? This research is starting from the personal observations that student enjoy making games and the motivation the feel from making and play testing their game overcomes any distaste or fear (see previous chapter) with maths. Finding research about students' experiences of learning (in particular maths) though making a game would backup these observation and peer validate this research.

Going back to Ke's study in the conclusion he states, "The survey results suggested that students have developed more positive dispositions toward maths during computer game making." (Ke 2014). Which from observation the researcher has witnessed about games design and learning maths. Ke (2014) study supports the ideology behind this research. Although the students where younger and the Games Design engine was more basic in nature and used more visual scripting (GameMaker has both visual and coding).

Ke (2014) assessed the math by testing the student's attitude to maths before the Games Design process and then tested their attitude after the Games Design process. This study reported that "Participants reported significantly more positive attitudes, including self-confidence, value, enjoyment, and motivation, towards maths after participating in the computer game making activities." (Ke 2014)
Ke (2014) also argues that students have a more positive attitude towards maths during the Games Design process. This observation that Ke (2014) saw is what this research has seen within the classroom environment. Another paper that discusses learning (though learning in general not just maths) was Garneli et al. (2018) where he discusses that serious games are a learning medium. This is a recent paper (unlike Ke's 2014 paper) that as Garneli et al. (2018) states "empirically examined different forms of serious-game use for learning" (Garneli et at. 2018). They used as in previous studies school children. One observation that Garneli et al. (2018) said that was of particular interest was "they did not believe that playing a game would have any influence on their maths performance. However, most of them mentioned that they enjoyed the intervention and that this activity made maths, as well as the educational software used in the learning process, more interesting to them." (Garneli 2018).

The reason this observation is of particular interest is this is what some of the students in this student have said in this research. Which reinforces this research initial assumption that games help with motivation. Students are more motivated when engaged with a game.

A study by Bruce et al (2004) looked at student's experiences of experiencing Jave programming. This research looked at students in the first year of a university course. A notable difference is that Bruces's student were at university (it can be assumed that they were older than a UK FE college student, who would progress to university after their FE course, however Bruce gives no indication of the age of the students) another difference is that Bruce's study is about student's experiences of learning Java programming language and this research is about experiences of learning maths through the medium of games development. One parallel that can be drawn between Bruces's study and this thesis's research is that a phenomenographical analysis was used to interpret the students' experiences of learning.

As much of this research is connected to phenomenography, parallels between Bruce's and this research are reflected on within the Discussion chapter of this thesis (see section 8.4).

Bruce reflected that from her analysis "some learning experiences may reinforce particular ways of going about learning to program" and further elaborates by saying that "teachers may wish to design learning experiences, tutorial activities or assignments that orient students towards the full range of possible ways of going about learning to program" (Bruce et al 2004).

This reflection by Bruce communicates that a program of study can be delivered in a way that enables a deeper learning experience. This is to say, a program of study can be designed to enable many different ways of learning a subject. This is a concept that is discussed in more detail within this thesis (see section 4.7)

3.6. Game design for teaching and learning

The discussion so far has been with regards serious games with maths but not the theory of how to implement Games Design. The context of this research is that the researcher is a full-time lecturer who is a part-time researcher. Understanding the pedagogical background of the different learning approaches. The role of the lecturer, the role of the student and the underlying learning theories is important to this process.

According to Hung et al. (2001) there are 4 models of learning: behaviourism, cognitivism, constructivism, and social constructivism. Huang et al. (2006) further simplifies this and says there are traditional pedagogies and active/engagement pedagogies.

3.6.1 Behaviorist and cognitive based pedagogies

Traditional pedagogies are based on behaviourist learning models that Skinner (1974) promoted and links with the famous "Pavlov's dogs" experiments where a dog responded to a bell ring. In this learning theory students are seen as a "black box type entity" that responds in a "cause-and-effect" way. In other words, an input is given and with an expect output. Behaviourism is also a theory of learning that believes learning occurs through a reward and punishment system that creates a change in behaviour (Duchesne and McMaugh 2018). The cognitive learning theory is about "Information transmission and processing" (hung 2001). That is students not only remember information they can apply rules and strategies to this information as well. However, they still don't have a deeper understanding of its meaning they can't apply this information. This information is still academic in nature to the student, just raw data. These traditional pedagogies are ones that have been used for many years and used across many different subject areas. Huang (2006) also categories traditional pedagogies as three types. Subject based, Cookbook laboratories and group work (Huang 2006). The traditional based teaching pedagogy and teaching style is a well-supported educational approach. The focus is the subject itself; resources include physical or digital textbooks which is referred to for content. The student is led through a step-by-step process (like following a recipe in a cookbook).

3.6.1.1 Teacher / student role traditional theories

These pedagogies are a teacher centred where students are taught from printed or digital resources and the students is given a test to see if they understand it. It's all about information transmission that is teacher led. The role of the teacher is to deliver the information to the student and control how and when this takes place. The teacher follows a logical step by step approach delivering content to the class. Giving the student information in a managed way. The student's role is to engage with this information and feedback what they have learned. However, a weakness of this approach is engagement. Huang (2006) argues that this approach "…does not engage students enough to result in substantial learning." (Huang 2006).

Is a student just repeating back information they have learned by rote evidence that they understand what this information means? Huang argues that traditional approaches "may lack relevance and context from the student's point of view." (Huang 2006). One criticism of more traditional pedagogies is the formulaic approach where a subject is delivered in a logical step wise manner, but students do not engage with it (as stated earlier). The classroom setting for this study is heavy technology based. The student is engaging with a variety of technologies to create a game. In this setting a teacher led approach may limit how the student engages with the technology and also may limit creativity and individuality as well.

3.6.1.2 Games / Games Design role traditional theories

From a Games Design perspective would these traditional approaches be useful? Lameras et al. (2017) discusses what role the teacher plays and what roles the students play in a serious Games Design process. Lameras et al. (2017) discusses that a teacher led role (which is applicable for traditional pedagogies) is to delivery content to the students such as the games making task description, what levels they could make, description of type of game to make etc. The student role would be to follow the teacher's guidance in a step-by-step approach as they made the game (Lameras et al 2017).

3.6.2 Constructivism and social constructivism

Constructivism learning theory is the principle that information that is stored in a mind has to be discovered and then constructed. Hung (2001) states that "learning is an active process of constructing rather than acquiring knowledge." (Hung 2001). So, it's not about gaining knowledge it's about how knowledge is constructed in the mind. This construction is depended on prior knowledge the subject may already have, a mind set a subject may be in and even the social context the subject is in. Social constructivism adds further element of how social interactions affect this construction. Hung states that social constructivism has "interaction with people – other children, parents and teachers – in cognitive development." (Hung 2001) Edgerton (2001) introduced the term "pedagogies of engagement" which links with this paradigm and is backed up by Huang (2006) also refers to active /engagement pedagogies. These more modern pedagogies have the underpinning elements of Constructivism and social constructivism learning theories within them. In constructivism learning theory a student has "Personal discovery of knowledge" (hung 2001). That is to say they relate to the information now and can apply it to other area and fields. Huang (2006) further says that engagement pedagogies "encourage students to be active participants in shaping their learning inside and outside the classroom" (Huang 2006).

In constructivism the focus is first on the student been a human being and then a leaner (Johnson 2014). In Humanism theory this goes a step further and, in this learner, centred theory the students free will is valued, the student has a choice what to what to think. Intrinsic motivation is used to motivate students and the student emotional wellbeing is considered. Johnson (2014) also argues that humanistic learning theory is a student-centred approach which is not just about them leaning and understanding but also it is linked to a student's emotional wellbeing.

3.6.3 Problem-Based Learning (PBL)

The basis of this teaching approach is based around a problem that needs to be resolved. "PBL is well suited to helping students become active learners because it situates learning in real-world problems and makes students responsible for their learning" (Hmelo-Silver 2004). It was observed in this study that as students made games, they came across an array of mathematical and game design problems which needed to be addressed. For example, a character not moving where it was supposed to do or graphical related issues that needed to be addressed. Problems encountered while making games is an inherent property that needs to be considered by employing a problem-based learning strategy. Barrows (2000) confirms this with his research. "PBL is focused, experimental learning organized around the investigation, explanation, and resolution of meaningful problems" (Barrows 2000).

The role of the lecturer within PBL is more as a facilitator and support as Hmelo-Silver (2004) puts it "The teacher acts as a facilitator to guide student learning through the learning cycle" (Hmelo-Silver 2004). This learning cycle is described later in Hmelo-Silver (2004) paper as Identify facts, Generate Hypothesis, identify knowledge deficiencies and learn new skills and then apply new knowledge to see if this overcomes the problem. The Lecturer leads the students through this process to teach them the basic mechanism.

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Fig 4 shows basis of PBL learning cycle adapted from Figure 1 (Hmelo-Silver 2004)

As can be seen in figure 4 a problem happens and for each student this can be different, also it can be the same (this is discussed further in collaborative learning). The student identifies the facts and from these facts come up with a possible hypothesis of what when wrong. They then reflect on their own skill set and knowledge base and learn and research what is missing and what they need to learn. This process is very important stage in this process Hmelo-Silver says this about this process.

> "An important part of this cycle is identifying knowledge deficiencies relative to the problem. These knowledge deficiencies become what are known as the learning issues that students research during their self-directed learning (SDL). Following SDL, students apply their new knowledge and evaluate their hypotheses in light of what they have learned." (Hmelo-Silver 2004).

So as can be seen the students are taking responsibility for their own learning. They are fully engaged with the process. However, for this process to work students need to be motivated. In fact, they need to be intrinsically motivated to work this problem. "Intrinsic motivation occurs when learners work on a task motivated by their own interests, challenges, or sense of satisfaction" (Hmelo-Silver 2004). For this to work effectively the students need to have knowledge base to start with and for the problem not to be so overwhelming that they can't overcome it.

3.6.4 Project-Based Learning (PjBL)

The Games Design process involved the student working through a list of tasks some of them complex in nature. These tasks include planning and creating original artwork, coding, level design, story writing to mention a few. Project-based learning (PjBL) is a model that organizes learning around projects (Thomas 2000). A project is a collection complex tasks that student works through to create in this case a computer game. It can be argued that the game they are creating is a form of a project. Thomas (2000:4) also says in order for a project to be defined as a project it needs to fulfil certain criteria such as: -

1) The questions or problems that direct the project.
2) A process that builds over time.
3) It's a student led process (teacher facilitated).
4) It is not a theoretical academic process, but practical implementation / process.

The process of Games Design is a constructive investigation (point 2 see above how this maps) which has lots of problems to overcome (point 1). Also, to address point 4 that the project is realist, it is realist in the fact a student does make a computer game and test it. It's not a theoretical exercise but a practical process a student works through. So, it can be seen that making a computer game fulfils the requirements that Thomas defines for what is needed for PjBL. Making a game is ideal within the pedagogy of project-based learning. Thomas (2000) argues that in PjBL that the role of a teacher is a facilitator of learning. He states that it is "teacher facilitation but not direction" (Thomas 2000).

Then it can be argued that role of the lecturer is once again as a facilitator and a mentor, guiding the student through all the elements involved in creation of a game (the project). He further states that "Projects are student-driven to some significant degree" (Thomas 2000). It is a student driven experience, with the student setting the pace and steps involved in the game development with feedback and reflection provided from the lecturer when required. One problem with project-based leaning is if the students don't manage their time well. As it is a learner-based process the responsibility is on the student not on the lecturer.

3.6.5 Case based reasoning

Case based reasoning (CBR) is a process of problem solving based on previous experience. Kolodner et al. (2003) argues that CBR "refers to reasoning based on previous experience" (Kolodner et al. 2003). In practical terms its where a new solution is based on experiences gained from past experiences (case). It increases the speed of learning. They then use the example of planning a dinner party, that the previous experience of planning a dinner party is used in the new situation (Kolodner et al 2003:502). Looking at this from a constructivism learning theory point of view, the previous experience is built on and developed.

3.6.6 Cooperative / Collaborative Learning

A definition of cooperative / collaborative learning according is according to Huang (2006) is that the learners are an environment in which they work together to achieve a shared goal. More specifically cooperative learning is described as "a set of processes which help people interact together in order to accomplish a specific goal or develop an end product which is usually content specific." (Panitz 1999). To add to this Huang (2006) also says, "Cooperative learning is highly structured". Panitz

(1999) also adds it is a teacher led approach. The students' work together working through a set of processed to achieve a common goal in a highly structured way led by a teacher. It can be seen that this pedagogy could work well with both the problem and project-based learning approaches described above. However according to Panitz (1999) this pedagogy can be teacher led, the teacher giving the structure and setting the tasks that need to be completed. A Games Design process is by its nature is a very creative process one which the students' needs artistic freedom to create a unique product. On the surface collaborative and cooperative learning are similar and are often confused. However, there are some key differences between these two learning styles. Panitz (1999) describes the core differences in who has authority over the process. For collaborative learning the testing is the responsibility of the students in the group, not the teacher. This then is clearly a student led learning method. Panitz (1999) then continues with cooperative learning and argues that the responsibility is not with the learners but with the teacher.

The major difference is process ownership. In cooperative process the instructor (lecturer in this case) drives the process and is responsible and in collaborative the students take responsibility for the process. Collaborative is a students led rather than teacher led pedagogy. If students are leading the process, it can be inferred that this is a less structured approach. This is backed up by Huang (2006) who says, "Collaborative learning need not be as structured" (Huang 2006). One difference that follows on from this is the motivation. With cooperative learning pedagogy as the instructor drives the process, they also provide the motivation to achieve the goal. So as mentioned above the motivation is hence extrinsic. With collaborative learning the students themselves take ownership of the process and they are intrinsically motivated to make the game. This is backed by Panitz (1999) who states that collaborative learning is "based on intrinsic motivation generated by interpersonal factors and a joint aspiration to achieve a significant goal." Panitz (1999) also adds "Collaborative learning shifts the responsibility for learning away from the teacher as expert to the student" (Panitz 1999). From the standpoint of making a game, the students can if they choose to wish to work together or independently. One of the goals of this research is to allow student to choose how they make a game. They are given "free will" and encouraged to explore creative ideas on their own. This uses the "humanism theory" mentioned earlier in this chapter. Some students however like to work collaboratively with others when making game, brainstorming ideas together in a creative melting pot. Understanding Collaborative / cooperative leaning facilitates the lecturer to better support the students better through this experience and helped in the underpinning pedagogical environmental aspects of this research journey.

3.7 Games Design approach

As stated, earlier students are engaged with making games. Some of these games are serious games (see methodology chapter later). These games are games with a maths element within it. So, in affect they are making a serious game. However, one important difference between the student making a serious game and a game is that the students are not aware they are making a serious game (see previous chapter with regards maths and fear). When teaching the maths aspect is played down with the focus just making a game, it however is a serious game even if the students are making even if they are not aware of it. One of the main differences of serious games to games is the serious element. Within this context it is maths more specifically the learning of maths. It can be argued that maths is learned in 2 ways during this research. The maths learned whilst the student is designing the game and more specifically the math elements they are including within their game and a secondary learning of maths once they play test (and other student peer test) the game. Ultimately this study was focused on the student learning maths whilst making a game with a maths element within it. When designing a serious game is there a common approach to use? On research a plethora of papers on serious Games Design was found on this subject. However, no common structure on how to design a serious game could be found. Lameras et al (2017) also echo's this observation "Current literature on the field of SGs is inconclusive as regards to the provision of a comprehensive analytical structure on SGs design". (Lameras et al 2017)
Also focusing on a specific design to take when making a game also would be indicative of a teacher led approach, one in which teacher would specify and lead the students through the steps in making a game. As discussed earlier the maths aspect is to remain hidden so a student led approach would help more in this fashion. The

Games Design process in this research is an unstructured student led approach. Lameras et al backs this up “The game design classification is perceived as a non-linear open-ended design process” (Lameras et al 2017).

3.8 Games Design as a learning approach

According to the constructivism theory knowledge is constructed through interaction and discovery. Designing a computer game is process where a game is constructed and developed in an iterative design process (see fig 5)

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Fig 5: Adapted and simplified UNITY gdlc Model (UNITY 2018), showing the three phases of making a computer game.

3.8.1 Design based learning

In Kolb's experiential learning cycle (Kolb 1984) discusses a four-stage learning cycle in which a learning moves from one place to another in the process eventually returning to the beginning.

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(Kolb 1984).

In Bellotti et al paper (2011) he discusses that "In Kolb's experiential model of learning, individuals are encouraged to reflect on the actions and consequences, so to foster understanding and reapplying this understanding to future actions." (Bellotti et al 2011). Comparing Kolb's experimental learning cycle with the Games Design development (see fig 6), in particular the production section both are cyclical in nature and Kolbs is about an experience with the game it's about a making a game and testing it. It can be argued that they are similar in nature. Especially if making a game is an 'experience' that a student is involved in. All this discussion leads to a concept called design-based learning (DBL).

Doppelt et al states that "DBL enables students to experience the construction of cognitive concepts as a result of designing and making individual, inventive, and creative projects, to initiate the learning process in accordance with their own preference, learning styles, and various skills." (Doppelt et al 2008:23). As discussed earlier in PBL a game can be considered a set of problem to be solved (Fig 6) adds to the argument that the creation of a game is a project. Kolodner et al (2003) when looking at design-based learning (Kolodner et al (2003) calls it "learning by design™") choose Problem based learning the approach as well in their research work. Design based learning is a new concept in education it is closely related to PBL and PjBL as well. In fact, Kolodner et al (2003) argues that PBL and CBR is part of a DBL approach. Baron and Darlington (2008) argue that students should be put in the role of problem solvers. They then add "In all problem-based approaches, students take an active role in building their knowledge, while the teacher's role is to make thinking visible" (Barron and Darling-Hammond 2008). This emphasizes that in this learning is student led and the teacher is a facilitator or learning. Arnab et al argue that "Through the playful design thinking process, the students discovered that fun could have serious and positive consequences and were challenged to innovate on how we deal with real world problems through a playful approach." (Arnab et al 2019). Doppelt et al argues that DBL is an active learning process that puts student in the centre of a learning process and changes the role of the teacher to "guide and partner" (Doppelt et al 2008) in the learning.

3.9 Summary of theories

As discussed, some ways of teaching are not as effective to student's learning maths as some others. Huang (2006) argues that the tradition learning approach "…does not engage students enough to result in substantial learning." (Huang 2006). Constructivism learning theory is the principle that information that is stored in a mind must be discovered and then constructed. Hung (2001) states that "learning is an active process of constructing rather than acquiring knowledge.". Also Hung argues that knowledge is discovered in a personal way (hung 2001). This means that rather than the knowledge being teacher led (or lecturer led), the knowledge is more student led. The student is encouraged to discover the knowledge on a personal journey. However, for this to take place this needs to be within a framework not as a stand-alone theoretical concept. This leads to a concept of games design as a learning approach. Doppelt et al argues that DBL can help in the leaning of new skill and is student led (Doppelt et al 2008:23). Design based learning [DBL] is and approach of learning through a process or framework. More specifically the design of computer games and the maths element within that process.

3.10 Conclusion

Serious Games Design-based learning is an open-ended educational pedagogy based on PBL which puts the students in the centre of the learning process. This student led process uses the intrinsic motivation of games. Lameras at al back up this up with "student motivation significantly increased especially for the student group that constructed their own game. Intrinsic motivation was highlighted as an important variation that can be enhanced through construction." (Lameras et al 2017). This research into serious games and serious games shows that they can be a powerful learning mechanism. For these reasons and with the constraints of this research design-based learning was chosen for the Games Design process. In the next chapter I will discuss how this pedagogy fits with the constraints of a classroom and the concept of "serendipitous learning environment" is introduced.

4. Serendipitous, Incidental and Stealth teaching and learning

4.1 Introduction

At a first instance the concept of serendipity feels and sounds almost metaphysical in nature. However, it is hoped this chapter can highlight the benefit of creating in essence a serendipitous learning environment to help in developing maths skills through a game development process. Serendipity will be explained in more detail later but in summary it is something that happens that is a "happy coincidence". This "happy coincidence" can be created and engineered in such a way to foster the learning of maths through the mechanism of developing a computer game with a maths element within it. Serendipity on its own is not enough through. As discussed earlier in maths and fear some students have an aversion to maths. In order to overcome that a form of stealth teaching is used to enable maths to be embedded (discussed in methodology chapter later). It is the combination of these two approaches that create this "serendipitous learning environment" that fosters maths learning.

4.2 What is Serendipity?

Serendipity is defined as unexplored and unplanned discoveries and fortunate incidents in the process of exploring something else (from the Oxford English Dictionary). The etymology of the word is linked to Horace Walpole in 1754. After reading the "The Three Princes of Serendip" he wrote a letter about this 'silly fairy tale' to his cousin Anne, Countess of Ossory, on 16 August 1776. In this letter he used the word 'serendipity'. Horace Walpole was the son of the then prime minister, Sir Robert Walpole.

4.3 Serendipity in learning

The word serendipity has itself come under attack by some, because of its apparent vagueness. However, this does not distract from what the 'essence' of serendipity is. In the context of the research done is it is 'planned'. It is the process of discovering unrevealed aspects, which in the context of this research is learning maths whist doing computer Games Design. So 'a happy coincidence' can take place. In their paper about students' experiences with massive online gaming Lombardi and Mark talk about the concept of "serendipitous encounters" (Lombardi and Mark 2004). Their paper was about finding ways to increase these "serendipitous encounters". In their research, these researchers created an online environment in which students playing an online game learned new skills to overcome challenges within a game they were playing. The researchers created the game and monitored how the students engaged with it. They observed that as students overcame these challenges, they learned new skills. This learning of skills was either cooperatively or individually, but it was unstructured and not taught directly, this research has some parallels to this approach. The parallels being the environment made, in mine the students make a game (and play it) they do not just play a game. The learning is not a taught process the students must follow. This is in essence student led learning.

Another concept that links with this is Planned Happenstance theory. In "Planned Happenstance: Constructing Unexpected Career Opportunities" (Mitchell, Levin and Kumbolz 1999) the researchers discuss the role chance has in employment and career pathways. They discuss how counsellors can coach clients to look out for "chance encounters" to increase employment prospects. Also, how employment agents can create "chance" encounters to approach prospective clients.
With "Planned Happenstance theory" a person/client is receptive to chance opportunities for employment. The same is true for students who are receptive for opportunities to learn given the right environment.

4.4 Incidental / Serendipitous Learning

Researchers and educators alike feel that there may an overlap between serendipitous and incidental learning. To expand on this Buchem (2011) says that serendipitous learning as a subset of incidental learning and then adds "learning through gaining new insights, discovering unrevealed aspects and recognizing seemingly unrelated connections." (Buchem 2011:13). The reason it is a subset is because serendipitous learning is always a beneficial or fortunate experience. Incidental learning is not necessary as powerful or as positive an experience, it can be negative. Also, incidental learning covers a whole host of informal learning experiences. Gritton (2013) also discusses that serendipitous learning is a subset of explorational learning and is part of the constructivist learning theory.

Whilst Egger (2008:189) talks about how serendipitous learning is undeniably taking place in workplaces and it is the person's inherent personal motivations that draw them to learn something. Buchem (2011:10) when talking about serendipitous learning taking place in social media type blogging as an accidental aspect. As a side note serendipitous learning is not just an academic curiosity it is recognised in commerce and industry as well.

In the non-academic world serendipity is recognised and utilised as a business concept. According to Steve Jobs biographer Walter Isaacson "Steve Jobs wanted the workplace to be optimally conducive to creating those chance encounters. "(Znet 2021) Steve Jobs wanted these discussions as serendipitous encounters within the workplace. Steve Jobs also said, "creativity is a result of serendipity" (Znet 2021). Interestingly Apples new 5B$ home was developed with some Steve jobs ideas of "serendipitous interactions" (Znet 2021).

All this leads to the fact serendipity is not just random chance it can be planned and implemented. Industry giants like Apple recognise the potential of serendipity and the concept of planning serendipitous encounters. It can be argued that one of the reasons for Apples success is the realisation of the power of serendipitous encounters within its culture and how an environment can be tailored to facilitate this. Part of this research was about tailoring an environment to facilitate serendipity.

4.5 Planned Serendipity

All this leads to the fact serendipity is not just random chance it can be planned and implemented. The concept of 'planned' serendipity seems to appear to be an oxymoron. However, this is because the general perception of serendipity is that it is unplanned (see initial Oxford dictionary definition). However, there is much evidence for 'planned serendipity' (as used and seen within the multibillion-dollar organisation Apple PLC see example above). In academic circles planned serendipity is also observed.

In their paper about students' experiences with massive online gaming Lombardi and Mark (2004) talk about the concept of "serendipitous encounters", which links with Steve Jobs "serendipitous interactions" (Znet 2021) concept. Their paper was about finding ways to increase these "serendipitous encounters", so in essence it is concept planned serendipity. Serendipity is defined as something that happened that is a "happy coincidence", however as discussed above and argued by Lombardi and Mark that "planned serendipity" can be used. Eagle (2004) talks about the concept of "serendipitous encounters" as well and how people in social situations are planning these 'bumping into' in moments with people that they wish to connect with in some way and "serendipitous encounters" (Eagle 2004; Lombardi and Mark 2004). Then serendipitous learning can be in fact planned if implemented correctly.

Lameras et al. (2017:10) argues that learning can be serendipitous or incidental when using serious games. This type of serendipitous (or incidental) learning that occurred all happened "as if by chance". In an unplanned or spontaneous way. However, Lameras et al. (2017:10) is not just implying this is not accidental it can be planned.

A big part of this research process is this seamless process of embedding maths within a Games Design process. The mechanics of the learning is taking place within the Games Design process as discussed in the previous chapter. However, the Games Design process is just part of the process.

This research is not just looking at serendipity. For the planned serendipitous learning to take place another element needs to be in place as well. One key component is a stealth approach.

4.6 Stealth Approach

The context for this research is education, more specifically a classroom environment where computer games is taught and learned. The goal is to find a way to embed maths, as discussed earlier a perceived subject some students avoid in a way that is hidden. The students that are involved in this research are all Games Design students. The students in this study are specifically creating serious games with a maths element. This Games Design is presented to the students is part of an overall assessment for the students to complete as coursework. This is where the concept of "stealth approach" is used.

For this research the assessment (in the form of an assignment see appendix and methodology chapter) is the embedding the maths element as part of a computer game they create. The students are expecting to make a game (they are enrolled on a games design course see methodology and appendix) the maths element is not the focus of the assessment from the student's perspective.

Shute and Ke (2012) argue that "During game play, students naturally produce rich sequences of actions while performing complex tasks, drawing on the very skills or competencies that we want to assess" (Shute and Ke 2012). This is the key for this model of teaching. The goal is not to extrinsically motivate them, the students of their own free will need to be receptive through an intrinsic motivation to make a game. The competencies this research want to assess is how the students experience making the maths game. Shute in many of her papers discusses embedding assessments within the very fabric of a learning environment. (Shute and Ke 2012; Shute, Iskandaria and Oktay 2010).

The result of the stealth approach to teaching is that students are unaware they are being assessed (maths experiences and maths skills), hence the phrase 'stealth' assessments. This concept that Shute is referring to is very close to the subject of this study but with maths being the assessment aspect represented in game making. Serendipity and a stealth approach to teaching link together in what I labelled a serendipitous learning environment. This link starts with the planned teaching environment which uses a stealthy approach of using maths (in the form of a card for this research) and the immersion a students get when engaging with the technology in the form of a game engine.

4.7 Serendipitous learning environment

All this leads to a concept within the research which is labelled "serendipitous learning environment". To better define this, it is where the learning that takes place 'seems to happen almost as if by accident', or serendipitous learning.
Most learning is teacher-led learning (behaviourist and cognitive theory), as in learning as a process or enforced structure. In the maths chapter the way some students view maths is problematic and processes need to be developed to deal with this. A teacher-led approach was not felt to be appropriate (see previous chapter). The answer was not one single element but lots of jigsaw pieces. Including a stealth approach, intrinsic motivation from the game design, to count a few. One aspect of this research was this open learning environment in which the students choose their own path and set their own goals to achieve the main goal of making a computer game (some with a maths element within it). As stated within the previous chapter this is a "student led" teaching process and the lecturer acts as a mentor / coach / facilitator of learning. Some students will need more "help" from the lecturer and for them they choose to have "more" support. Some others after initial input from lecturer they would work on their own and "figure out" how to make a game by themselves with no support from the lecturer. They "take responsibility" for their own learning.

This "serendipitous learning environment" is one that facilitates the learning of a subject which for some students is feared or they have apathy (see section 2.9). The maths subject is embedded with the fabric of a course and course assessments. One of the key factors is a stealth way of a) embedding the maths subject within the making of a game and b) the way the game making process is discussed with the students throughout the course. A serendipitous learning environment also is one in which the students' own intrinsic motivation to learn is used to overcome their barriers to learn a subject some have struggled with in the past. The students use a technology based (games design) serendipitous learning environment in which they are free to explore and self-learn (Humanism) and work with others if they want to (Collaborative). These aspects can become a framework that can be repeated in future classes. This concept is also discussed within Bruce et al (2004) research where she reflects on how learning experience can be enhanced by teachers design learning experiences for students (Bruce et al 2004).

In summary the "serendipitous learning environment" included a stealth approach similar to Shut et al to embed the maths elements (Shute and Ke 2012; Shute, Iskandaria and Oktay 2010). It also includes Design Based Learning (DBL) approach (Doppelt et al 2008; Barron and Darling-Hammond 2008; Arnab et al 2019) where students are free to work in teams, which is collaborative learning (Panitz 1999). As this is a planned process, this is "planned serendipity" (Lombardi and Mark 2004; Lameras et al 2017; Eagle 2004). All this was taking place utilising "Humanism teaching theory" (Johnson 2014).

4.8 Conclusions

This concept of serendipitous learning and environment was first observed with the confines of a games design process. It was believed that the concepts and processes discussed where and, in some ways, a personal belief an intuitive teaching style that this research has always used. However, on reflection and backed up with research, it is shown that this secondary and environmental concept of serendipitous learning combined with a stealth approach is used within the entire research process and links closely and work with design-based learning. It is embedded within the entire underlying philosophy of the research journey and can be shown as a viable repeatable process that supports teaching and learning. This all culminates in a “Serendipitous learning environment” that consists of many aspects that link together as an almost a background ideology that permeates the entire research. It consists of many aspects that link together. The game design process immerses the students with the experience, the stealth approach introduces the maths elements and the open-ended student led pedagogy used within the classroom all facilitate the learning. If the stealth approach learning is the seed, then serendipitous learning environment is the soil for the seed to grow in.

5. METHODOLOGY

5.1 Introduction

In the previous chapter on maths, immersive technologies and pedagogies are all specific to the main research taking place. The mathematic chapter discusses the 40% failure students have in passing maths at GCSE level. Discussing the factors that affect this such as "fear of failure" / students' frustration of doing what is perceived as a pure academic subject. Lack of motivation and engagement, etc. The use of immersive technologies and how students are intrinsically / self-motivated to use these technologies and how they are and have changed the landscape of education. The FE policies chapter is the environment students are working in and the impact this has on them, students have left school and are in this next educational step and how funding of FE impacts a student education etc. Then the pedagogies chapter is a discussion on the different teaching styles and the impact they potentially would have the students as well.

This research attempted to address key questions that needed to be looked at as primary research. These questions where:

1. Can students learn maths whilst making a computer game with a maths element within it?
2. How student's experience learning maths through making a computer game?

This chapter presents the overall research philosophy and strategy used to address these questions. It outlines the rationale and philosophy of the quantitative approach and the qualitative approach adopted for this study. The research design is perpetuated on a sequential process. There were three stages to the research. The pilot study stage (see chapter 6), the main RCT study stage and then the phenomenographic stage. Each phase was an experiment and a test to see what worked and what did not work and why and then what could be done differently for another stage of the study. The pilot study stage was an attempt to exert preliminary outcomes, to streamline the research process such as overall appropriateness of methodology, recruitment aspects, data collection and analysis procedures. The main RCT study stage was in some ways an extension of the pilot study RCT trials, incorporating lessons learned from initial stage and then repeating new study with a new group of students. The phenomenographic stage purpose was to gather deeper nuances of students' holistic experiences of learning maths through a game design process. All three stages sequentially followed on from each other with the last two stages learning from the pilot study stage. The researcher was a full time FE lecturer in a college running game design courses this study was done within the context of teaching and delivering these Games Design to these students over approximately a 5-year period.

This chapter will discuss the rationale behind the research design and methods, focusing on the following aspects: -

- Describe research stance
- Describe the methodology behind each of the three study phases.
- Rationale for quantitative and qualitative approach and the mixed method.
- Discuss each of the research phases and how the research moved from phase to phase.
- Describe the data collection approach.
- Discuss the ethical considerations used within this research.

5.2 Research stance

The focus of this research was to investigate if students learn maths through games and also through understanding their experiences of making games.
The researcher is acting as an unbiased observer of students' engagement in a Games Design process (phenomena), obtaining knowledge in the form of maths tests (which relate to the quantitative stance) and semi-structured and open-ended questions to students as they complete making the game (qualitative stance using phenomenography). "The positivist epistemology is one of objectivism. Positivists go forth into the world impartially, discovering absolute knowledge about an objective reality" (Scotland 2012). A positivist epistemology approach means that the researcher is an impartial observer of the world and take knowledge from this. "A

tree in the forest is a tree, regardless of whether anyone is aware of its existence or not" (Scotland 2012). In this statement Scotland argues that in a positivist's research stance that the tree is a specific knowledge area which can be found. In the research I am doing the tree is the student's experience of engaging with maths. A problem with this approach is bias, if the observer has a bias, it can change the perceived reality and the observed results. The issues of bias are discussed further on in this chapter in more detail. One aspect of the pilot study phase was to identify some of the biases so they can be eliminated from the subsequent studies.

5.3 Main study overview

Although the results from the Pilot study (see chapter 6) was encouraging it was always felt that there was a need to look deeper into what was really happening with the students' experiences when engaging with the Games Design process.
The limited question in the pilot student qualitative approach were very limited. A deeper more qualitative approach was needed. Hence the phenomenographic approach was taken and this was done in parallel to the RCT trials. These two stages are very different research approaches, but they were logically and sequentially linked to each other. The RCT for the main study was seen as 'supporting' the phenomenographic stage. However, the RCT stage was the first step of the main study, in it the students make the games (this time without the researcher also teaching this set of students to address a bias limitation discussed in pilot chapter) and their maths skills are assessed before and after the game making process. Then immediately after they make the game, they are interviewed using a phenomenographical approach (all this is discussed in section 5.3.2).

The phenomenographical data was then needed to attempt to get a deeper picture of the experience of learning maths within the context of making a computer game. Could a perceived experience of learning maths map with statistical data from the RCT data?
To summaries the mixed method approach was seen not just as gathering students' experiences (phenomenographic stage) but seeing if these experiences could be linked to maths skills learned (addressing RQ1 and RQ2).

5.3.1 RCT study stage design

The pilot study revealed that some maths learning was taking place and some students were aware of learning maths. How do you stop students using maths they already know? The answer is to give a single path that is more challenging. One in which they are using maths they don't know as well. The pilot phase looked at the whole maths skill set used by students they learned as part of their maths GCSE.

This second phase focused on a specific area in maths. The initial assessment (BKSB) was used to get a base maths assessment (See BKSB RCT rationale in detail in section 5.5.1). From this BKSB data a specific maths weakness that was observed in the students (See BKSB appendix for more details on BKSB maths assessment questions).

The students were randomly chosen for either group to test the hypothesis that intervention group (labelled experiment in Fig 7) would be statistically different than the non- intervention group (labelled control in Fig 7). (See also Appendix 4) Experimental plan for RCT study, for how this was practically planned within the teaching curriculum of a FE college.

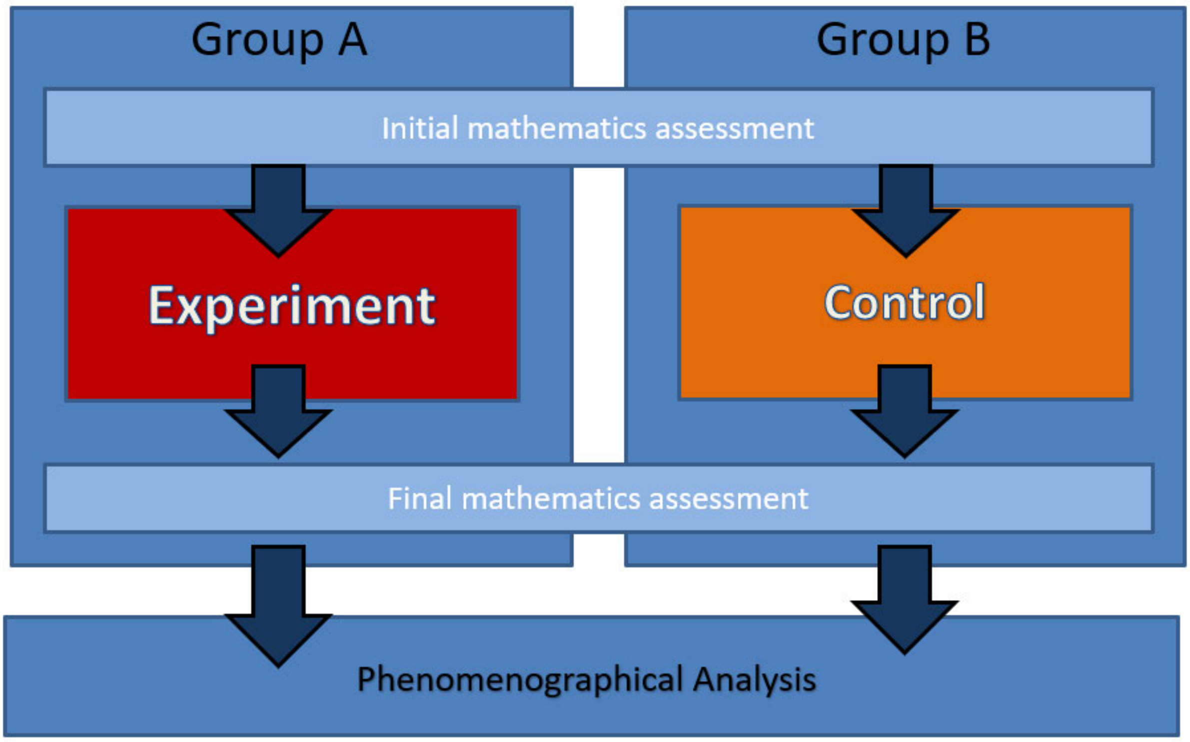

Fig 7: RCT and Phenomenography studies overview diagram

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Exercise 1 **Independent Events**

Show all answers to the following questions as simple fractions.

1) If you draw a card from a full deck of 52 playing cards what is the chance that it will be:

a) the ace of spades? ________

b) the queen of hearts? ________

c) a king? (There are 4 kings in a pack of cards.) ________

d) a picture card? (There are 12 picture cards in a full pack.) ________

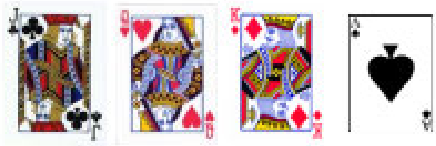

Fig 8 - taken from a test paper BKSB NWSLC college has. This test is showing one of the probability questions that are asked (see Appendix 9: BKSB test paper for more examples of questions asked). The level of these questions is equivalent to GCSE level.

The proposed intervention was to create a game which had a maths aspect to it. The rationale behind the game choice of a card game was that the pontoon card game involved drawing cards until a score of 21 (or as near to 21) could be reached. The maths aspect in this game is probability. The player would need to know what score they had (and also computer player's scores) and use probability to decide whether to 'twist' or 'stick'. The BKSB maths assessment also asked questions which involved cards and card games (see fig 8 above), so this made the intervention more appropriate and relevant. Another aspect of this intervention was a perceived weakness from the pilot; that when the students made a maths game, they used maths they were comfortable with. Choosing the same game concept for all would help with this problem.

Once both sets of students made their games then all the student completed a second BKSB test. After this and but for sake of fairness to the students made the other game, so they completed two games by the end of the academic year (the students were required to make 2 games as part of the course curriculum, the second game was outside the scope of the RCT). One of the challenges of this study was to work within a normal teaching curriculum and not artificially add the research to a curriculum.

5.3.2 Phenomenographical stage design

As seen in figure 7 once students have completed both games, they interviewed on a one-to-one basis by the researcher. This is where the phenomenographic study takes place, immediately after the RCT stage using the same students. In the pilot study students had an exit interview consisting of 10 questions that looked at some of their experiences in making the game. These questions were not seen as enough questions for a phenomenographic approach, and more questions were added to the interview process. The rationale for the phenomenographic approach has been discussed earlier but in summary its purpose was to delve deeper into the student's experience (or phenomenon) of the Games Design process with a maths element in it. The games were part of an assignment that was developed and influenced by Shute research (Shute and Ke 2012) (see Shute's stealth assessment process discussed in the serendipitous learning chapter). But unlike the stealth assessment process as discussed by Shute, the assignment was used to contextualise the learning process where explicitly the learning activity was contextualised as a game design process but with maths was stealthy embedded within the process. This links with the concept of the serendipitous learning environment theme discussed throughout this thesis.

The students were interviewed about the games design process and their experiences of designing a game (not assessed on any game they made). This study focused on the students that did the experiment (made the game with the maths element) and compared them to the students in the control group. Students from both groups took part in the interview to gain as much variation as possible in the experiences of games design.

According to Booth (1997) "Phenomenographic research has tackled questions concerning the variation in ways in which people experience the phenomena they meet in the world around them." (Booth 1997). The qualitative stance at this stage as to look at and test a Phenomenographic approach to getting the students experience of doing the Games Design process. Bruce also argues "all questions should lead the interviewee to discuss how they see, experience or understand and a subject" (Booth 1997). More specifically Bruce argues the questions "seek variation in peoples experience or understanding the phenomenon in question" (Booth 1997).

The phenomenon in question for this study was students' experience of making a game with a maths element within it. The questions are unstructured to semi-structured and are mostly open. These questions would allow the interviewee to freely express themselves and use their own emotional language and reflect in their own way how they experienced the Games Design process. Particularly in relation to how they experience the maths element within the Games Design process. As show in maths and fear background research chapter discussed earlier on in this thesis direct discussions about maths with the students or giving students an awareness that maths is been accessed directly is problematic. This phenomenographic 'test' was to see how the students responded. It was expected that the initial questions which had no focus on maths would make the students more comfortable than asking about maths from the get-go. Then as more questions were asked then more maths specific question could be asked and also given the openness of the questions it would allow them to use emotional vocabulary. These students whether they were voluntary involved in the study or not were enrolled on a computer games course. The students were making games as part of an assessed assignments and graded on them. The questions student was asked were all around these assignments. Also, it was felt to keep the question to a minimum at this stage of testing phenomenography.

These interviews where audio recorded for subsequent transcription to keep the interviews free flowing. Herbert and Pierce state when they did interviews for qualitative research "The interviews were audio-recorded for subsequent transcription" (Herbert and Pierce 2013). All students were told all interviews would be anonymous and no mention of their names would be used in any findings hence the use of student1 to student30. As discussed earlier a qualitative approach was tested for the pilot study to see how the students engaged with maths within the Games Design process (mainly for RCT purposes). For the purpose of the pilot study only 10 questions were asked from general questions to more focused questions about maths. For the purpose of the pilot study the students made 2 games. To recap the experimental groups made a puzzle game, these puzzles are math puzzles. The control group made a platform game. (See Appendix 4: Experimental plan for Phenomenography for practical plan of implementation).

5.4 Rationale for quantitative and qualitative approach.

The rationale for the quantitative and qualitative approach all comes from the initial research questions that were chosen for this study.

> RQ1: Can students learn maths whilst making a computer game with a maths element within it?
>
> RQ2: How student's experience learning maths through making a computer game?

5.4.1 Quantitative rationale

Starting with the research question (RQ1). How can we test to see if a student learns maths? There are various ways to assess maths skill testing that a researcher could have taken. This research is done within the context of a teaching curriculum by a full-time educator. Some of the methods are more subjective in nature, such as direct questioning, observation, and interviews (and these were used as well in the qualitative approach). However, the best way to get a statical value is a maths test that students can complete who are part of the study. During the pilot study one system is tested but was abandoned because students felt it was unfair doing multiple maths test at the beginning of the course (see section 6.5).

The student enrolled on any college course are automatically mathematically assessed in what is called a 'initial assessment process' using a professional testing system that the college uses called BKSB (see section 5.5.1). This system tests the student and gives a percentage grade back of their maths results as well as a simple breakdown of the maths strengths and weaknesses (but only as a guide). This initial BKSB was used as an initial measure of students (all college student) maths competency. However, for the study a way needed to be developed to see if students learned maths when making a computer game. A method that would allow the researcher to represent the effect of learning maths via Games Design was Randomized Controlled Trials (RCTs). A RCT is predominantly used in medical research and employs a controlled trail in which people are random allocated to one of two available groups to test a clinical intervention (Stolberg et al 2004:1539). For this study the intervention is a game with a maths element within it. Stolberg et al argues that "Randomized controlled trials are used to examine the effect of interventions".

What affect does make a game with a maths element have when compared to the game without the maths element within it? This led to a statistical approach to testing this data. There are different ways this can be done, the students T-test, Mann-Whitney U test, Spearman etc are some of the examples of tests than can be carried out on a sample of data. The choice of which test comes down to whether the data is parametric or non-parametric in nature. Parametric data is one that follows a predefined pattern, or a normal distribution curve (sometimes called a bell curve) and non-parametric data does not follow a standard predefined pattern.

To summarise the RCT is used to test the RQ1. Also, for RCT we need an intervention (the experiment discussed later) to test the hypothesis that "students learn maths when they make a game with a maths element within it" and comparison, this is in effect the control where a set of students make a game with no maths element within it. Also, for RCT is that students were randomly allocated to either the intervention group (see experiment described later) or the Comparator group (see control described later) and also the student volunteered (discussed later, see appendix section for student volunteer sheets) for this process. The expected outcome is that the intervention group learned more maths than the comparator group. In other words that the hypothesis that hold true ($p < 0.05$) (discussed in more detail later). Also see appendix 4 for experimental plan for RCT study.

5.4.1.1 Why use RCT rather than a simple experiment?

A simple experiment would involve the students making the game (the intervention mentioned above) and there would be no control group. This test would show a snapshot of before and after maths skill levels. Even though this would be a far simpler test to do, there are some fundamental issues with this approach. The first one is simply the fact that we have no way of knowing if the maths they learned was from the maths they put *in* the game or the maths they learned from the coding to *make* the game. The RCT process involved having two games made in parallel where both need coding, but one (the intervention) has the additional maths element included. When the maths test was completed for both sets then this differentiation could be exacerbated.

5.4.1.2 Criticisms of RCT

No discussion of RCT is complete without a look at some criticisms from academic scholars. An important factor here is context. This research for this thesis is done in the field of education using an immersive technology, a games engine. It is relevant to look at academic research from the education background.

> "Chaos and complexity theories here are important, for they argue against the linear, deterministic, patterned, universalisable, stable, atomised, objective, controlled, closed systems of law-like behaviour which may be operating in the world of medicine and the laboratory, but which do not operate in the social world of education" Morrison (2001: p. 72–4)

Here the author criticises RCT for taking a complex system such as the concept of learning in a classroom and trying to simplify it into a rational linear result.
Another researcher Elliott adds to this by saying that within education, research

> "takes the form of case studies rather than randomised controlled trials. The latter, via a process of statistical aggregation, abstract practices and their outcomes from the contexts in which they are situated. Case studies entail close collaboration between external researchers and teachers on 'the inside' of an educational practice." Elliott (2004: 175–6)

These researchers see the use of RCT within an educational practice as ignoring the context in which the research is conducted and the experience the participants (students) are engaged within. The RCT in simple terms is trying to simplify a complex system that takes place within an educational system down to a "cause and effect" equation where the "cause" is the teaching of a subject and "effect" is the results of any skill increase.

This criticism is why RCT is not used as the only or even the primary 'evidence' gathering tool used in thesis' research. RCT is used because it is seen as a useful tool for gathering statistical evidence of a skill level (in this case a maths skill). The RCT is used for RQ1 which asks whether students learn maths.

5.4.1.3 Is the data parametric or non-parametric in nature?

Data from a human being about their IQ, height, weight, blood pressure is all parametric in nature (McLeod, S. A. 2019). Therefore, it can be assumed that data from a person that shows maths skill test is parametric data. The researcher has found no literature to discount this assumption. A parametric test is required. T-Test is a widely used parametric test and it is a null hypothesis testing approach. The Null hypothesis testing is a formal approach to deciding between two interpretations of a statistical relationship in a sample.

> One interpretation is called the null hypothesis (often symbolized H0 and read as "H-naught"). This is the idea that there is no relationship in the population and that the relationship in the sample reflects only sampling error. Informally, the null hypothesis is that the sample relationship "occurred by chance." (Chiang, Jhangiani and Price, 2020)

In layman's terms if the null hypothesis is true then there is a high chance of statistical error, random chance / variation. How do we measure the null hypothesis? The research finds the p value, the probability value. A low p value means that that null hypothesis is false, and a high value means it's true. The research that is been done is testing the hypothesis is that students learn maths when making a computer game with a maths element within it. How do we deal with the fact that students may learn maths by just making a computer game? This is the rationale behind the experiment, which just involves making a computer game. If we look at the mean difference between the results of the control versus the results of the experiment, then this hypothesis can be checked. The null hypothesis check is to see if the difference is something else other than the hypothesis itself in question. A low 'p' value would indicate that the data is pointing towards the hypothesis that is been tested. In simple terms when the maths data from the tests is obtained it can be tested statistically to see if it's just random luck a student learned maths or is a statistically measurable increase? The t-test enables this to take place.

For t-tests to work 2 set of data are needed and this is from the 2 groups of the RCT. In RCT the students were randomly allocated to either set, using a simple method of putting students' names into a hat and then randomly drawing name out. One set is called control and the other is the experiment that is been tested. This means the RCT was a single blind study, as in that one of the groups the student was allocated to was to test to see if student learned maths in it and their experiences in doing so. One of the main purposes of randomising which group is in is to reduce bias (Stolberg et al 2004:1539). The bias in this instance would be a researcher choosing the allocation of which group to put students in. However, as Stolberg et al argue the randomness does not remove all bias (other bias discussed later on) (Stolberg et al 2004:1539). As far as the students were concerned, they were making two games but making them in a different order to the other students, the real nature of the study was hidden from them. The hope was that this cultivated an environment for serendipitous learning of maths to take place.

5.4.2 Qualitative rationale

The research question RQ2. Is asking about a student's experience of learning maths. The quantitative study provided the grounds to explore whether students could learn maths through making a game. In order to elicit deeper experiences on how students perceived learning maths via game-making necessitated a more relational and interpretive approach to the research. This resulted in a distinct quantitative approach to address this question and eventually resulted in the use of phenomenography. Phenomenography is an interpretive approach that seeks to identify the range of variation in ways of perceiving or experiencing a phenomenon of interest (Marton and Booth 1997).

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Fig 9 The subjects' experience of the phenomenon in question as the focal aspects in phenomenography.

Figure 9 shows a visual representation of phenomenography, and it can be seen the researcher is not looking at the experience, they are looking at the subject's experience of engaging with the Games Design process. Or a 'second order perspective'. In fact, the researcher is capturing the essence of a user's experience and attempting to understand it in an unbiased, impartial way. Marton was one of the first researchers to this was to coin phase phenomenography and he pioneered the initial research in this area. Marton was a researcher and educator in university looking at students. Marton describes phenomenography as 'second order perspective' (Marton 1981). The specific of this study is to use phenomenography to see how attempts to understand how learners ***experience*** the maths elements within a Games Design process. Sandberg (1997) argues that "Instead of taking the researcher's perspective as the point of departure, they argued that it is necessary to adopt the learner's perspective on learning" (Sandbergh 1997). Phenomenography allows the researcher access through rich data obtain through open ended questions the "why and how" a student learned or didn't learn maths. This approach is essential in getting the full picture of these experiences. In the pilot study a basic qualitative approach was used but (as will be discussed earlier).

In this main study a more in-depth phenomenographical study was developed with the RCT seen more as supporting role.

5.4.2.1 Criticisms of phenomenography

One of the criticisms of phenomenography is that doing the same experiment to another set of students would not get the same categories of description. This is because interview data is a unique snapshot in time of a conversation between the researcher and the student. Marton observes that researchers using phenomenography also recognise that individuals may hold different conceptions of various aspects of reality over time (Marton, 1981, 186). This is seen as an advantage according to some researchers. Also, Cossham states that "This is a more realistic approach for user studies than one which looks for a single understanding because it allows for variation across a group of research participants" (Cossham, A.F. 2018).

5.4.3 Mixed methods rationale

The initial hypothesis was that students would learn maths whilst making a computer game with a maths element within it. The results from the pilot study (section 6.2) showed that maths seemed to be learned but more research was needed. Looking at the statistics of the maths learning did not give a clear picture, more was needed. This then led the research on a mixed method approach to a get a clearer picture if possible. Also, research question RQ1 is a quantitate based question and RQ2 is qualitative based question, and this then informed the two research strands taken.

5.5 Justification of data collection approach

As discussed, the research has two main stages pilot and main, both had qualitative and quantitative approaches with the quantitative approach seen as supporting the qualitative approach.

5.5.1 BKSB RCT data collection justification approach

When a student enrols on any course at the college their maths and English skills are tested. This an "initial assessment" and its purpose was to see what support they may need on any given course of study with the college. For this "initial assessment" the college uses a professional testing system called BKSB. BKSB is an online testing tool used by most educational establishments in the UK. According to the

BKSB site "89% of colleges use our products – that's more than 580,000 college learners, who may be studying Functional Skills or GCSEs" (BKSB 2021). This professional online assessment tool is an impartial, unbiased assessment process that allows students' maths (and English) skills to be assessed (BKSB 2021). It gives the results as a percentage and allows further breakdown into specific mathematic areas such as understanding numbers, calculations, ratios, fractions, decimals, percentages, formulae, money and time, units of measure, perimeter and area, volume, 2D / 3D scale, statistics, and probability. So specific maths skills weaknesses and strengths can be identified. BKSB has been used by other researchers as part of a RCT (Szifris et al 2018; Groot et al 2017; Hume et al 2018).

As discussed in the FE and Mathematics chapter, some students have a low tolerance of maths and some even have a fear of it. This assessment was automatically given to all students as part of the enrolment process for all courses within the FE college. Students did this test regardless of whether they were involved with the research. In the pilot study a separate maths test was also used for maths skills assessment. From discussions with students during the pilot study, students felt doing another "maths test" was unfair or even a form of punishment. Using the official BKSB test results helped with the 'stealth approach' of embedding maths in the Games Design process (see Stealth approach in Serious Games and Learning chapter). See Appendix 7 for more information with regards BKSB.

To summarise, the rationale behind using this BKSB as part of the data gathering approach was that: -

- The students all did this BKSB "initial assessment" process to test their maths skills and the data is given to all lecturers teaching those students.
- BKSB testing is professionally used by 89% of all UK colleges and is an impartial, unbiased assessment tool that tests students' maths skills and gives a breakdown of specific maths strengths and weaknesses. (BKSB 2021)
- From discussions with (and observation of) students, some would feel that an additional maths test would be 'unfair' to them when compared to their peers not involved with the research.

- BKSB is used as part of RCT process by other researchers. (Szifris et al 2018; Groot et al 2017; Hume et al 2018).
- Only using the BKSB test results meant the students' low tolerance / fear of maths was not aggravated. They knew the tests were for all students and that it supported them in their college studies.

5.5.2 Phenomenographical data collection approach and rationale

Students enrolled on a Games Design course had an expectation of creating a game. This game was part of an overall assignment that they were given. The data collection approach was embedded as part of an assignment (see appendix 6). All students were expected to present their game and have a discussion with the course tutor with regards to their game. The students demonstrated their game and discussed their game design process and created documentation or a short video.

As discussed in this thesis, one potential barrier some students have is their view of maths. From observation and informal discussions some students have, as Pouyamanesh and Firoozeh (2013) discuss, a low frustration to maths and some as Putwaina and Symes (2011) discuss, a 'fear of failure'. This assignment was developed and parallels Shute's research (Shute and Ke 2012; Shute, Iskandaria and Oktay 2010) within the course design from the start to 'hide' the maths element (see appendix 1,2,4,5,9,8) from the students. From the student's perspective they were creating a game. A card game and a space invader game to be specific. They have been randomly selected to create either the card or space invader game first (RCT process is to support the phenomenographical approach). The course in effect had been subtly designed to enable the stealth approach, without the student being aware of this. All students were interviewed, however the students who volunteered were asked Phenomenographical related questions as well as the questions needed to be asked as part of the Games Design assessment. This approach further hides the experimental design from the participants (the volunteers knew that they were part of PhD research study however not the specifics of the research). For the Phenomenographical questioning (see appendix 5 as well) a stealth approach was adopted by asking some general questions at first then questions about Games Design then moving onto questions on learning maths. This concept is part of the overall concept of a serendipitous learning environment first discussed in chapter 4 (section 4.7).

For example, asking the student "*What did you think of this assignment then?*" Was seen as a good starting question as the students would be expecting to be asked this question and it was hoped to put them at ease. The student's had expectations that these questions were about the games they were making. This set the tone of the questions and initially focused on these games and how they students felt with regards these games. So, asking direct questions from the start about maths could potentially trigger a reaction of fear or frustration. However, asking them "*So can you give me an example of something you have learnt?*" would be a safer question and potentially allow the student to volunteer information about experiences with regard maths. This decision was taken early on to ask more general questions about making the game's first to facilitate a rapport with the interviewee before asking more on more maths related questions later once the interviewee opened. When they would be better able to talk about their maths experience. For the purpose of the Phenomenographical stage the questions were split into 4 sections.

- General Question
- Questions about Games Design
- Questions about Games Design with a view of learning maths
- Concluding questions.

The initial general questions were designed to be broad enough to obtain meaningful response in relation to the aim without forcing a particular structure or way of responding from the participant. With the questions will eventually direct the student towards the phenomenon in question. Some of the questions were seen as core questions such as. "*When you created the game how did you feel about using the maths elements within this game? "*

After the interviews had been concluded, the data collected (called scripts) was analysed to study the students' experiences. Alsop and Tompset (2006) explain that

"Each account is one description of one experience, which is limited by what was perceived by the individual at the time and considered to be relevant on this one occasion". This data is a snapshot in time just after the game development process, when the game making process and the maths engagement is fresh in their memories. So the first process of phenomenography is to analyse these fresh experiences. Booth (1997) says "The researcher is expected to 'step back consciously from her [sic] own experience of the phenomena and use it only to illuminate ways in which others are talking of it, handling it, experiencing it, and understanding it" (Booth 1997) So it's not enough just to read, the researcher needs to maintain an unbiased approach. An approach of structured reading is used. Each script is analyzed "The researcher tries to carry out the analysis for one theme or aspect at a time, simultaneously looking for overall patterns formed by the various aspects and how these aspects are related to one another" (Booth 1997). So looking for these themes or conceptions is the key to the phenomenography. These themes or conceptions form what is known as the categories of description. These categories are logically separate but are hierarchically linked to each other. These themes or conceptions are how the student engages with the Games Design process. The variation between the categories is also important. The researcher is looking for 'meaning' from all this data processing. The outcome will show how the varying ways of experiencing a computer game with maths in it are seen by students.

5.6 Ethical Considerations

According to Resnik (2021) the most common way of defining "ethics" is "norms for conduct that distinguish between acceptable and unacceptable behaviour" (Resnik 2021). What is acceptable behaviour and what is unacceptable behaviour within the context of research? One area that people value is privacy the ability to protect one's personal details such as name, age, address, telephone number etc. Hammersley and Traianou (2012) calls this concept autonomy "Protecting individual autonomy has long been a central principle in Western moral-political thought". An acceptable research behaviour is to protect the participant's identity within the research.

The age of students was between 16 and 19 years old. From research point of view, it was clear that a separate group was needed within the main Games Design group to be part of the experiment. The rest of the group not doing the experiment was still making the same games and within the same environment as well. One early consideration was the age of the students and students who were younger than 18 were excluded, this was mainly to comply with Coventry University ethics process / simplify the ethics process. Even though all students were in one form, or another involved in the experiment, this did not mean that data from their results or interviews would be used. To comply with Coventry universities ethics students were asked if data from their results could be used outside the college. This data would be anonymised so student's names would never be used. A consent form was created and students who wished to participate within this study completed the consent form (see appendix 1 and 2). Also, any students could at any time opt-out of the process. These forms were kept secure using the college systems (appendix 1,2).

5.7 Summary

In simple terms the mixed method approach was used for a variety of reasons. The research questions themselves leaned towards both a qualitative and quantitative approach to be used. The students 'experiences' required a qualitative approach that can look at this objectively. A phenomenographical approach is a qualitative approach that uses a second order perspective, this can be used to look how a student experiences maths. Secondary to the phenomenography study is a RCT quantitative approach. The RCT is a tried and tested way (see section 5.4.1.2 Criticisms of RCT) to get a non-biased viewpoint of statistical information, which is ideal for determining a student's maths skill. In addition to this both games the students make have a coding aspect this can be seen as a maths element itself. The RCT approach removes the question of whether a student learns maths as a side effect of doing coding, when both the experiment and the control use coding to make the games.

One final aspect is sample size. The RCT study is a small sample size of 30 students, this is a small sample set for a RCT study (give references). The phenomenographical study is 7 students which is a small size for a phenomenographical study on its own but as this is a mixed method it is argued that 7/9 adequate for this mixed study. A final minor aspect is that given the time constraints and research limitations it was seen to be the best approach.

6. PILOT STUDY

6.1 Introduction

The pilot study stage was a small scale (n= 26) preliminary study conducted to evaluate the post-qualitative stances chosen. Lancaster, Dodd, and Williamson define a pilot study as "one of the important stages in a research project and is conducted to identify potential problem areas and deficiencies in the research instruments and protocol prior to implementation during the full study" (Lancaster, Dodd and Williamson 2004). The rationale for the pilot study was to test the instruments in preparation for the main RCT study and later for a phenomenographical study. The data collected in this study was viewed from this standpoint and was used to feed and direct the main study but not be used beyond this stage. This study consisted of two phases: a quantitative and a qualitative phase. The pilot study design is shown in figure 10 below.

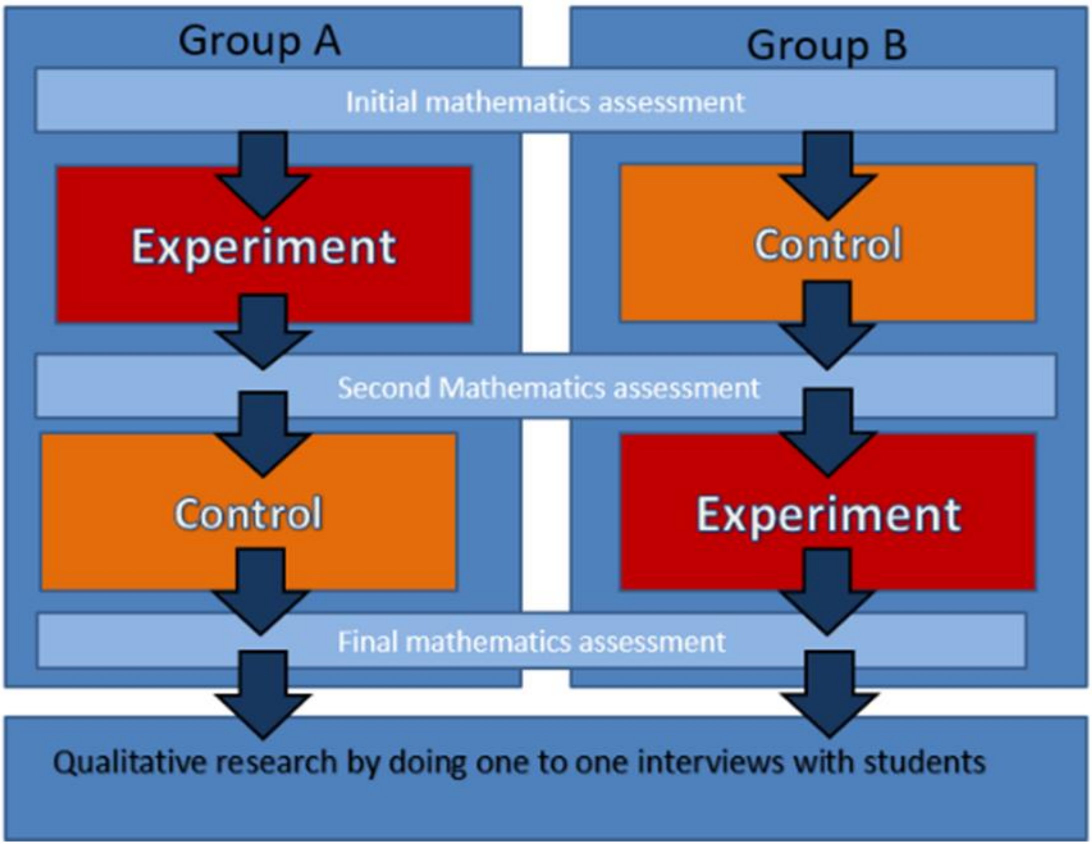

Fig 10: Showing the quantitative and RCT phases within the pilot study.

As stated earlier the researcher was also a full time FE lecturer teaching Computer Games Design. The subjects for the pilot study were all the lecturer's students and after the study was introduced to the students (in a much-simplified form and without mentioning maths) 26 students agreed to take part (ethical approval process is discussed later with regard to this process).

All students used college laptops with 'Gamemaker' software installed (see fig11) and had wireless access to the college network and internet and were part of a larger student body who were not part of the study but who also created both the games described in the methodology.

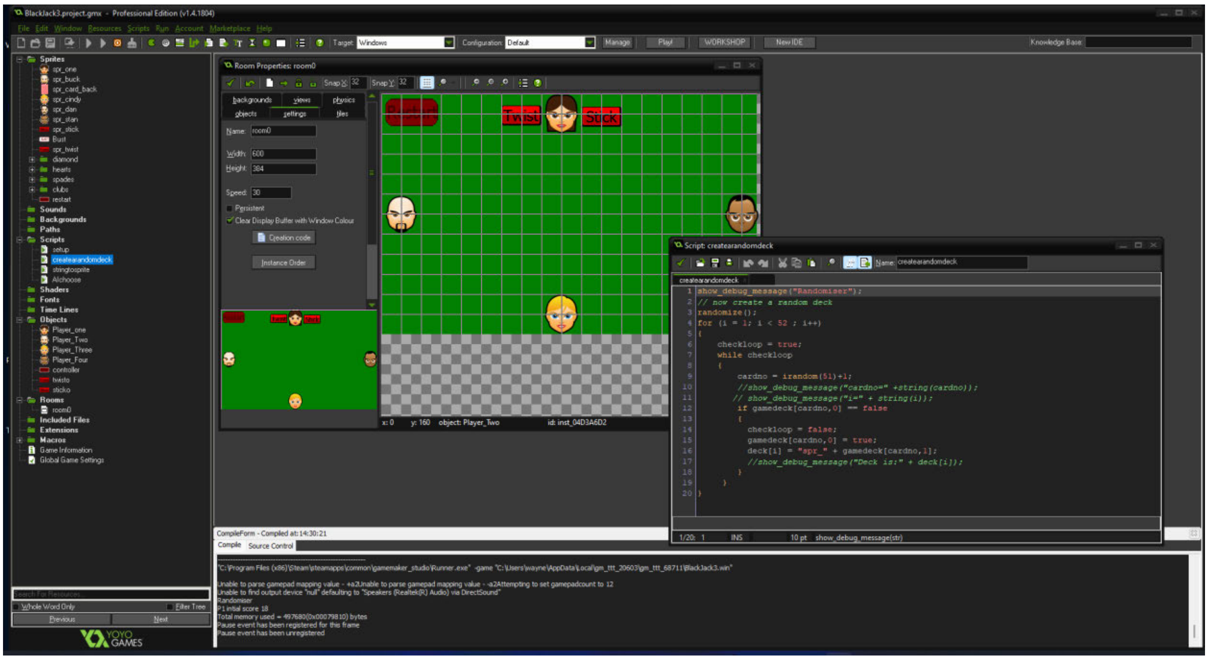

Fig 11: This shows a partially made card game using Gamemaker game engine.

GameMaker game engine is a 2D cross platform software that is appropriate for beginners in game design. It allows the students to create a 2D based game using simple menu-based system. It uses both visual based coding and a script similar in nature to JavaScript. Students can create pixel like sprites using this engine or use Photoshop for more artistic concepts. GameMaker also allows students to add assets like sounds. The Diagram in fig 11 shows a game being developed with a code snippet as well as sprites on a background.

For the pilot study a maths test was found online to test the student's mathematical ability. This maths test was done in addition to the college's initial assessment (BKSK discussed later) which also included a maths test. The students completed two separate maths tests at the beginning of the course. The students were randomly allocated to either the experiment groups or the control groups as shown in fig 10 above (part of a Pilot RCT). The two experiments took place in parallel. The experiment group had students who were tasked with making a computer game with a maths element within it and a control group who made a computer game with no maths elements within it. Then as they both completed the first game another online maths test was given to both groups to test their maths skill again. After this test the groups were swapped, and the students then made the other game as shown in fig 10. At the beginning of the Games Design course the students were told they would be making two games, that half the class would work on one game and the other half the other game and then at some stage they would swap and make the other game. As far as the students were aware, they were just making two different games. They were not aware that one game would have a maths element. These two games were of the students own design and within the constraints of the basics of newly learned game making. They were basic 2D games, such as shooters (space invaders), platform games (Super Mario like) or puzzle games. The experimental group mainly used puzzle games in the form of platform games where a player had to answer maths questions or in the better games a more visual maths problem to figure out how to progress and gain score.

6.2 Testing the Pilot RCT process

The focus of the pilot study was to test how RCT worked with this group of students and get some preliminary findings. The purpose of the RCT was to get these two data sets so a t-test could be used to see if statistically, students in the experimental group (i.e. the group that made a game that had a maths element in it) learned more maths than the students in the control group. It was hoped that the students would have three maths tests (see fig 10). However due to a situation outside the researchers control only two could be done (the initial and second one). However, this did not affect the data as the experimental group could still be tested against the control group (as required by RCT).

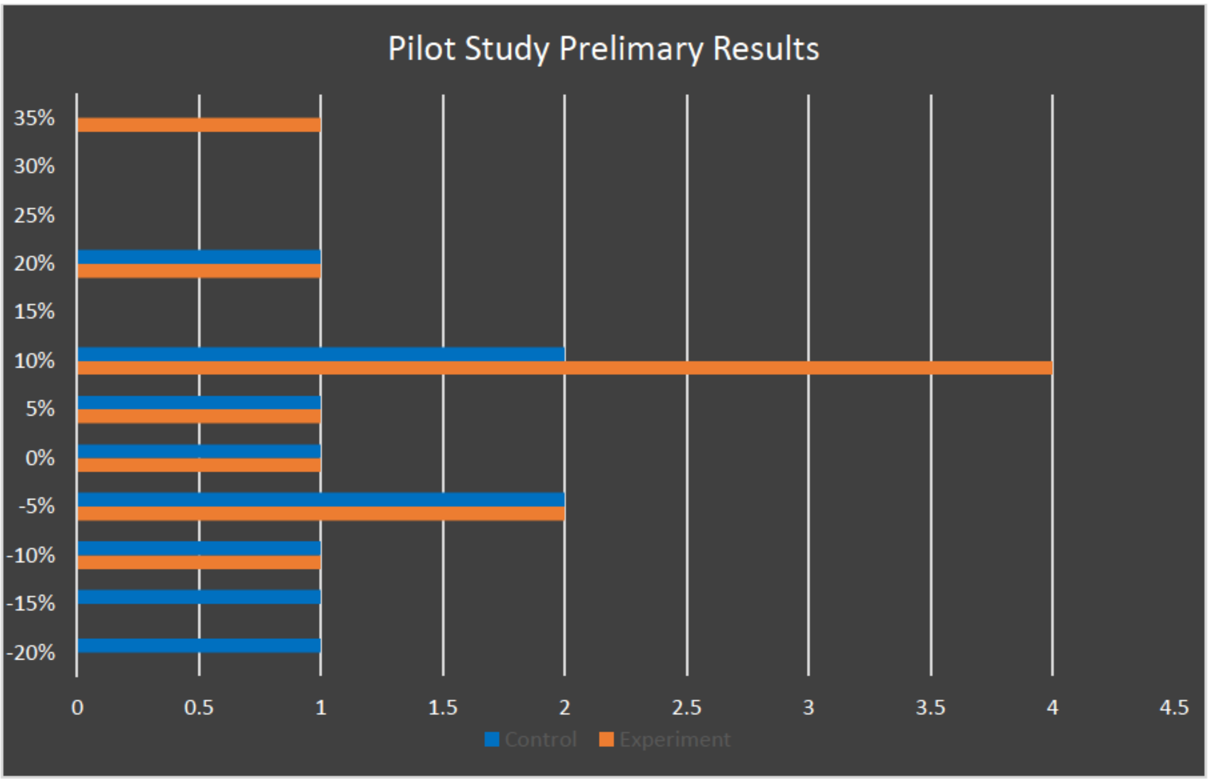

Fig 12: Pilot study Bar Chart of preliminary results minus outliers from experimental and control group for the pilot study. This bar chart shows the contrast between experiment (yellow) to the control (blue).

Figure 12 shows the data from the experimental group compared to the control group. At first glance they appear similar, however looking deeper, four students had an approximate 10% maths skills increase in the experimental group compared to just two students in the control group. Also, at the lower end of the scale two students from the control group had poorer results (-20% n=1 and -15% n=1 for control group) and no students in the experimental group had a result less than -10%. To summarise, the results of the t-test on the data between the initial assessment and second assessment resulted in $p = 0.25$. As $p > 0.05$ there is no significant difference between the gain in score between the control and the experiment groups for these assignments (this means that statistically it could not be proved that they learned maths). There was also a large standard deviation of: 5.2 (control) and 5.9 (experiment).

The control's mean gain was 0.6 and the experimental group's mean gain was 3. That seemed to indicate that during the same period the experimental group had learned more maths than the control group. On reflection it could be seen that the research was worthwhile and needed pursuing. The pilot RCT preliminary findings were encouraging and although it could not be proved that students had learned maths, some very valuable lessons were learned from this Pilot RCT stage. These initial findings showed that the RCT process needed refining and needed further investigation on what worked and what did not. This is where the qualitative interview process became essential in gathering this information.

6.3 Testing the qualitative approach

The focus of the pilot study was always on the RCT aspect with a limited qualitative process seen in a supporting role. The limited qualitative process started with an exit interview with each of the students who completed the trial and with a series of ten questions asked. This qualitative aspect was about testing the approach of understanding how the students experienced maths within these games they were making. The students made two games. The experimental groups made a maze puzzle game, these puzzles were in the form of maths puzzles. The control group made a platform game. As discussed earlier these students were all enrolled as Games Design students within a college. They were expected to create two games as part of this course and this pilot study was embedded within that process. The main purpose of the study was hidden from the students. The students were told that only their game design process and the games they made were looked at. The first question was just to settle the student and find how they felt when they made the game (the game was part of an assignment). They would think about the games they made in a general way without maths being mentioned. Then the questions would get gradually more and more focused on the maths part of the design. One question that was hoped to open up the discussion was on something they had learned (Q3). The final question would be a direct question about whether their opinion towards maths had changed.

The 10 questions were: -

1. What did you think of the assignments (both of them)?
2. How would you rate the assignment (easy/hard/difficult)?
3. Give me an example of something you have learned during these two assignments?
4. In the platform game, name one thing you learned during this assignment?
5. In the maze game name one thing you learned during this assignment?
6. Did you learn maths in these assignments?
7. Do you feel you gained any maths skills when developing the puzzles for the maze game?
8. How do you rate your maths?
9. How hard did you find the maths?
10. So has your opinion of maths changed during the course of these assignments?

The students responded well to the interviews and engaged well with the process as they saw this as part of an assignment they were doing (not as part of the research, even though they had agreed to be part of the study).

However, some only answered 'yes' or 'no' to the questions, in these cases further questions were asked to probe deeper. The students were chosen for the interview because of the spread of results they had from the RCT results.

Student 7 who had an 8% rise in maths said the following when asked if they had learned maths:

Q: "Did you learn maths in these assignments?"
A: "To a degree yes."
Q: "Which assignments and why?"
A: "Err in the maze game because I had to think of questions that I could implement and had to work them out so that they had answers that correspond with that wasn't too hard also weren't too easy"

They were aware they had learned maths.

The initial five questions were asked before the students were asked any direct maths related questions. They were simply used as a key word search tool to identify what common key words or phrases students said. In the analysis the word 'maths' came up 8 times (7 students with 5 answers each so a 22% hit rate on maths) in their responses. These students mentioned maths with no prompting from the interviewer on the subject. This is an impressive percentage for the initial set of questions and shows that a lot of the students, at some conscious level, were thinking about maths. Some described the maze game as the "maths game". They were not conscious of the significance of this and swapped out "maths" and "maze" from time to time during these conversations. This seems to indicate that students are subconsciously reflecting on the subject and using "maths" in place of "maze" because they are aware of the maths element. When interviewing the students their answers are showing an awareness of maths and developing maths skills. An example of this is student 21 when even though when asked directly about it they said.

Q: "Did you learn maths in these assignments?"
A. "No because everything I put in the game I already knew."

Q. "Did you learn maths in these assignments?
A. "No well erm it depends which way you look at it because... maths no but the way in which you apply... like, well, I learned how code requires maths. That's the part that I learned. I have not learned any maths from it but learned like a mathematical sort of how can I put it the mathematical background, behind coding. How you need to make these sort of calculations in order to... like the health bar... erm in order to make the health bar work you need to have something, an equation of something, like hit points in variables … You can see where the maths is and how it's applied."

This shows that they are applying new maths methods and techniques to the game and are developing maths skills in an indirect way, which is the point of this experiment.

6.4 Did I learn maths?

During this exit interview a more subtle issue was discovered. Some students chose to use maths they knew and were comfortable with when making the game with the maths elements in. For example, student 21 from the experiment.

Q: "Did you learn maths in these assignments?"
A. "No because everything I put in the game I already knew."

It could be assumed they were not learning maths as such, just reusing maths knowledge. However, the data from the RCT showed he had a 10% increase in maths results from the test. Which contradicts the measured increase.

For another it was different experience.

Q: "Did you learn maths in these assignments?"
A: "To a degree yes."
Q: "Which assignments and why?"
A: "Err in the maze game because I had to think of questions that I could implement and had to work them out so that they had answers that correspond with... that wasn't too hard also weren't too easy" [Student 7]

Student 7 had to work out a maths puzzle and got an 8% increase in maths score. Both learned maths but only **one** was aware that they learned maths. This observation from the interviews was repeated with some other students. A way of delving deeper into this phenomenon was needed. From this it was decided that a phenomenographical approach would be used in future qualitative substages. Also, from the interviews it was clear (and shown in example above) that some students used maths they knew and felt comfortable with. They did not get a maths increase. How many tried to learn new maths skills? How many used existing maths skills? What impact did this have? This was a harder issue to resolve at first. The BKSB system that was used allowed a breakdown of the maths skills that were tested. From this, the students could be specifically directed to an area they were weak in, then they could not reuse maths skills they had already learned. This revelation opened a pathway for a more in-depth RCT approach to be used with a more tailored experiment setup that focused on a specifically identified mathematical weakness.

6.5 Reflection on Pilot process

The purpose of a pilot study is to test the instruments of the research and get some preliminary findings. This pilot was to look at an RCT and have a separate qualitative approach, asking students about the games design experience. Several key problems were discovered from this pilot that helped with the main RCT design and the phenomenographical study that followed.

During this process it was discovered that some students were doing maths GCSE resits and that as part of these resits these students were doing further maths studies in separate sessions in the college or even external sessions with private tutors outside college. One of these students had a 48% maths skill increase but was this maths skill increases due to any maths they undertook as part of this pilot study? The purpose of the experiment that was undertaken as part of the Games Design course was to test if students would learn maths intrinsically (self-motivated) within the college environment. If students were doing the experiment in college and then undertaking additional maths classes, it was impossible to see if they learned maths in the external classes or as part of the experiment. It was seen that this may account for the large standard deviation from the pilot RCT of 5.2 (control) and 5.9 (experiment). This connects with a t-test of $p = 0.25$. As $p > 0.05$ then null hypothesis is not upheld. It was decided that in future if any student were doing any maths resits, they would not be included in the experimental data (they would be part of the course of study however).

One more potential weakness was observed by another researcher and that was of bias (this is discussed in the Methodology chapter). If the researcher doing the experiment was also teaching the students during the experiment wouldn't their own bias affect the results of the experiment? One of the concepts of RCT is that students are randomly allocated to groups in this study. However, if the researcher is also the lecturer teaching these students wouldn't it still be classed as bias? This was a difficult problem at first to work around but then two more Games Design lecturers were employed at the college. Then for the main study the researcher became the course leader and had both these new lecturers teach the students doing the experiment for the main study. So hence removing themselves from teaching the students and removing their influence (and hence bias) from the experiment for the main RCT study.

One more problem arose from the students themselves. They felt that doing two maths tests (the college BKSB based one and separate online maths test) was as one student said, “this is unfair”. One of the research concepts was to discover how students experienced maths. The fact that the students did three maths tests in total (2 from online as part of pilot and college based BKSB) meant that students were very aware that they were doing maths compared to their peers who were only doing one test (the BKSB). This created a bias towards them not liking maths. From this it was decided to use the college based BKSB initial assessment process, as all students did this regardless which course they attended. Using the BKSB for the RCT also helped as part of the ‘stealth’ approach used later in the research.

All these revelations set the tone for future studies. It was decided to get the students to create games with maths elements that they did not know well and do a deeper interview process to find out their experiences of making these games. This first study was peer reviewed, published and then presented at the 2014 International Conference on Interactive Mobile Communication Technologies and Learning in Thessaloniki (Gallear, Lameras and Stewart 2014).

6.6 Conclusion

The purpose of a pilot study stage was to get some initial preliminary outcomes, to streamline a research process and look at how appropriate a given methodology, recruitment aspects, data collection and analysis procedures would be. Also, how the data from the pilot study would inform the main study methodology.

The methodology used in the pilot was a mixed method, with a focus on quantitative analysis and an initial attempt at qualitative analysis. The quantitative analysis proved successful, and some good results were forthcoming. Reflection on these results will help the main study later.

The qualitative analysis was limited for the pilot study, and it was felt much more was needed. This is discussed in the main study as well as the rationale for choice of phenomenography (see section 5.3.2).

It was felt that the pilot study was a good springboard to conduct further research with more emphasis on a qualitative approach, specifically a phenomenographical based study.

7. RESULTS

7.1 Introduction

This chapter presents the quantitative and the qualitative results from both the RCT study phase and the phenomenographical study phase presented in the Methodology chapter. These studies encompassed quantitative and qualitative findings to address the research questions the study sought to investigate. This chapter shows and discusses the findings from these two methodological strands of research.

7.2 Reflections from pilot study.

The pilot study was seen as a way of testing the equipment of research, testing a RCT and testing a qualitative approach. The data analysis for the pilot study was done within the pilot study chapter but reflection on these results is useful. This data was also seen as preliminary results and was not included beyond the context of the pilot study.

7.2.1 RCT summary

The average increase in maths skills from the experimental group was 8% and the average increase in maths for the control group was 2%. This is a 6% maths increase from the experimental to control group. A t-test on the data between the pre- and post-test results, resulted in $p = 0.25$. As $p > 0.05$ there is no significant difference between the gain in score between the control and the experiment for these assignments. A large standard deviation of 5.2 (control) and 5.9 (experiment), was discussed in the Methodology chapter, for some possible reason why this is the case. The results from the pilot are seen as preliminary findings and as such not added to the main study results.

7.2.2 Qualitative summary

During the pilot quantitative interview process the students where asked a variety of questions. Maths was not mentioned during the first five questions, but students mentioned maths with no prompting from the interviewer on the subject. This indicates that the students, at least at some conscious level, were thinking about maths within the game. Some described the maze game as the 'maths game' as well. They were not aware of the significance of this, and they swapped out the words "maths" and "maze" from time to time during these conversations. This seems to indicate that students are subconsciously reflecting on the subject and using "maths" in place of "maze" because they are aware of the maths element.

Later when students were asked if they learned maths, they said a variety of answers including: -

"No because everything I put in the game I already knew."

"No well erm it depends which way you look at it because... maths no but the way in which you apply... like, well, I learned how code requires maths. That's the part that I learned. I have not learned any maths from it but learned like a mathematical sort of how can I put it the mathematical background, behind coding. How you need to make these sort of calculations in order to... like the health bar... erm in order to make the health bar work you need to have something, an equation of something, like hit points in variables … You can see where the maths is and how it's applied."

The simple analysis indicated that the students experience maths in a variety of different ways. This indicated that a phenomenographical further study was needed.

7.3 RCT study phase

The pilot study identified weaknesses in the processes used in the experiment. The purpose of the experiment was to test to see if students can learn maths whilst making a computer game with a maths element within it. The pilot study was partially successful in this endeavour and some weaknesses were discovered and discussed in the Methodology chapter in detail.

The experiment for the main study was designed to eliminate these specific weaknesses in maths. One final minor issue was bias. In the pilot study the researcher was also the lecturer teaching the class. To remove any possible bias the researcher may have, they stopped teaching these students. This is discussed in more detail later in this chapter. A stealth approach (section 4.6) was further used to reduce bias of student's potential appreciation in engaging with maths.

To clarify, the RCT study phase was with n=30 students (out of 68 actual students taught). The rationale behind choosing the 30 students was as follows: -

1) They were students who volunteered to participate in the experiment.

2) They were students who had GCSE grade C (now 4) in GSCE Maths and were not doing additional maths classes as well as games design sessions (as discussed above).

3) All students who wished to be part of the study completed a participant consent form. (see Appendix 2)

According to Robson convenience sampling involves "choosing the nearest and most convenient persons to act as respondents' (Robson et al 2017: p141). The sample set for my research was the nearest and most convenient persons - FE students that had enrolled on a games design course. The target research was a specific cohort of participants with a population of n=68. This research's sample size (n=30) doing the RCT was quite high (44%). These excluded participants redoing GCSE maths resits and who wished to be part of the research.

As with the pilot study students did a maths test before and after they made the game (pre and post results). The pre results are shown in fig 13, the post are shown in the second column in fig 13 – please see below.

ST1	73%	68%	-5%	st9	78%	94%	16%
ST2	63%	82%	19%	st10	85%	89%	4%

ST3	46%	60%	14%	st11	86%	65%	-21%
ST4	65%	85%	20%	st12	78%	89%	11%
ST5	60%	72%	12%	st14	92%	90%	-2%
ST6	75%	89%	14%	st14	80%	94%	14%
ST7	89%	94%	5%	st15	76%	76%	0%
ST8	44%	70%	26%	st16	73%	73%	0%
st24	61%	73%	12%	st17	82%	84%	2%
st25	39%	59%	20%	st18	24%	29%	6%
st26	35%	47%	12%	st19	69%	75%	6%
st27	45%	63%	18%	st20	45%	53%	8%
st28	43%	57%	14%	st21	57%	61%	4%
st29	25%	31%	6%	st22	65%	53%	-12%
st30	76%	80%	4%	st23	53%	55%	2%
Mean	56%	69%	13%	Mean	69%	72%	3%

Fig 13: RCT trials results showing pre and post results and the difference between them. The results in red are from the experimental group and the results in blue are from the control group.

When analysing the data, the mean for the experimental group is 13% compared to 3% for the control group. This is a 10% increase from control to experiment group. Which is a significant increase of maths skills learned for the experimental group versus how much maths was learned in the control group. A t-test to check the validity of the data shows that the null hypothesis holds with the datum given. T-test result 0.003553 < 0.05 so null hypothesis holds. Using a percentile graph shows this swing more clearly. Both the experimental group and the control group used coding as part of the game's development process.

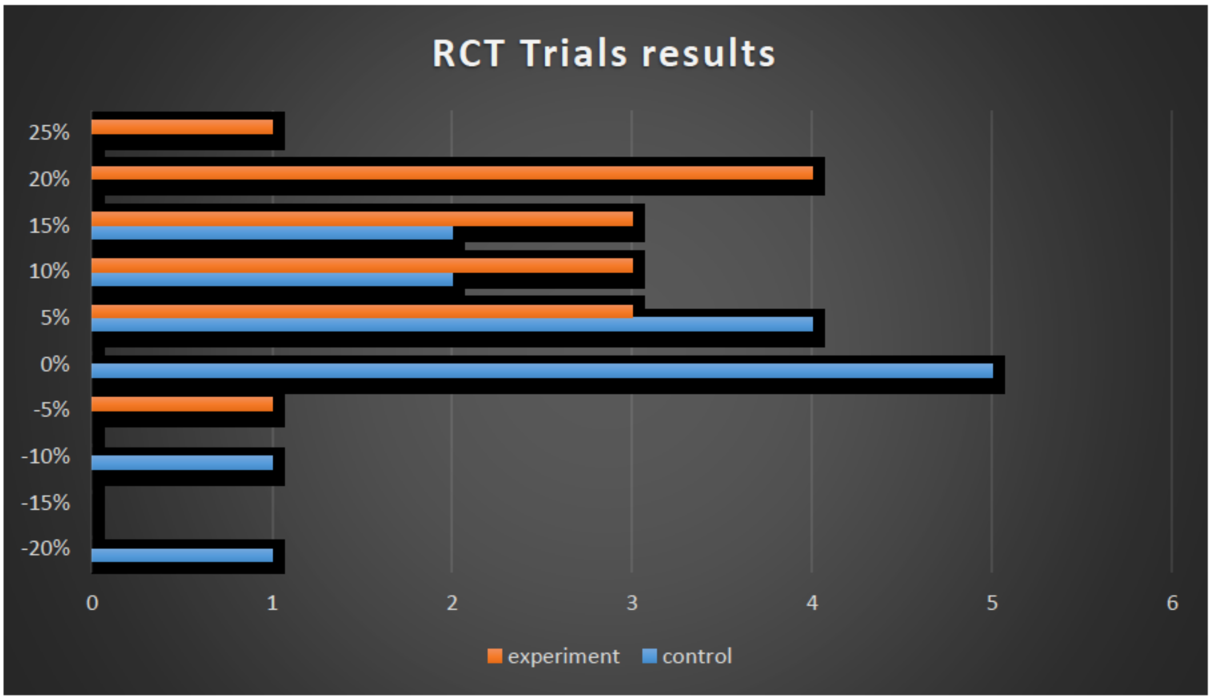

Fig 14: Percentile bar graph of results using data from figure 13.

The graph in fig 14 shows the percentage increases that students got in their maths skill test result after the game as compared to their maths skill at the beginning of the process. The horizontal axis is the number of students, and the vertical axis is the percentage increasing in maths pre to post experiment. The orange bars represent experiment results (the card game) and the blue bars represent the control measure (space invaders game).

The RCT mean of the results of the experiment is 13% and the mean of the results of the control is 3%. The graph shows the percentage swing difference form the control group to the experiment group (mean of 10% increase). The students making the 'control' and the 'experiment' game both did coding as part of the games making process. It can be argued that for the control group, the mean of 3% increase (seen in the control mean) is for the maths learned as part of the coding and hence the additional 10% is for the additional maths used to make the card game (experiment).

To further elaborate, five students in the control group had no noticeable increase in maths skills (0% increase show in blue bar on fig14). Whereas four students in the experimental group had a 20% increase in maths skill. On the lower end of the chart one student had 20% and one student had 10% maths skill decrease compared to only one student with -5% maths skill. Statistically the data seems to indicate that students from the experimental group did learn more maths that the control group. This is not conclusive proof that students in the experiment group learned more maths than the control group. Compared to the pilot study results (see Methodology chapter) there are clearer indicators that maths was learned. It should be stated that this data is from 30 students (out of 68 total doing the course in different groups) who were selected because they had all passed maths. As discussed in the pilot study, students who failed maths GCSE were doing additional maths classes. How could it be proved that students learned maths in the study if they had attended additional maths classes?

It should be stated that 30 is recognised as a low number for an RCT. The study in this thesis is a mixed method approach and the RCT is linked with a phenomenographical approach.

7.4 Phenomenography results

7.4.1 The Bias issue

As discussed earlier a potential, perceived difficulty that the researcher had with this process was bias. The researcher had a bias of wanting a mind changing to be seen in the group. To overcome this issue for the second study the researcher did not teach these students, it was done by a colleague whose focus was teaching the whole class. This colleague had no idea who in this class was part of the study and who was not. The researcher only had data from the online math test that all the students completed. Also, they performed the interviews at the end of the game making process. The rationale behind this is it was hoped this technique could be used in future by other lecturers to help students learn maths.

7.4.2 A deeper dive

The participants in the study represented a range of the student population, including some students who were studying computer science classes which now include a games design unit and students doing a pure Games Design qualification. Of the 30 students doing the RCT trials seven of these students were chosen for the phenomenographical study four were male, three females. All had turned 18 during the academic year and all formed part of the experimental group. The rationale behind these seven being chosen was mainly due to curriculum time constraints and these seven seemed to be, from an RCT point of view, a good cross section of the student body and were all open to the interview process. None had previous experience of creating computer games and all indicated that they struggled with maths in the past. A series of open-ended questions were put to the student volunteers on a one-to-one basis just after they completed their game. These questions were open ended and additional questions were asked if needed to clarify points if necessary. Why (and how) do some students learn to enjoy maths and develop maths skills during serious games development? The questions students were asked were at first general about what they thought about the assignments. Gradually the questions became more focused about the types of games, then to specific question about maths elements within the games. The questions were not closed and rigidly structured. Further questions were asked sometimes depending on answers and how the student was engaging in the process. The lecturer and researcher frequently observed the students during the games design process and informal conversations took place with regard to the games design process.

The questions asked can be seen in the Methodology chapter. (See Appendix 5)

7.4.3 Categories of Description

The category of description was from a phenomenographical standpoint; how a student described an experience they were undertaking. The students were all making a game with a maths aspect to it (a card game). These described experiences, when analysed, formed four categories of description. One aspect of a category is that participants (students) can be in multiple categories of description.

The categories of description were: -

1. Creative Approach
2. Experimental approach

3. Collaborative approach
4. Coding Approach

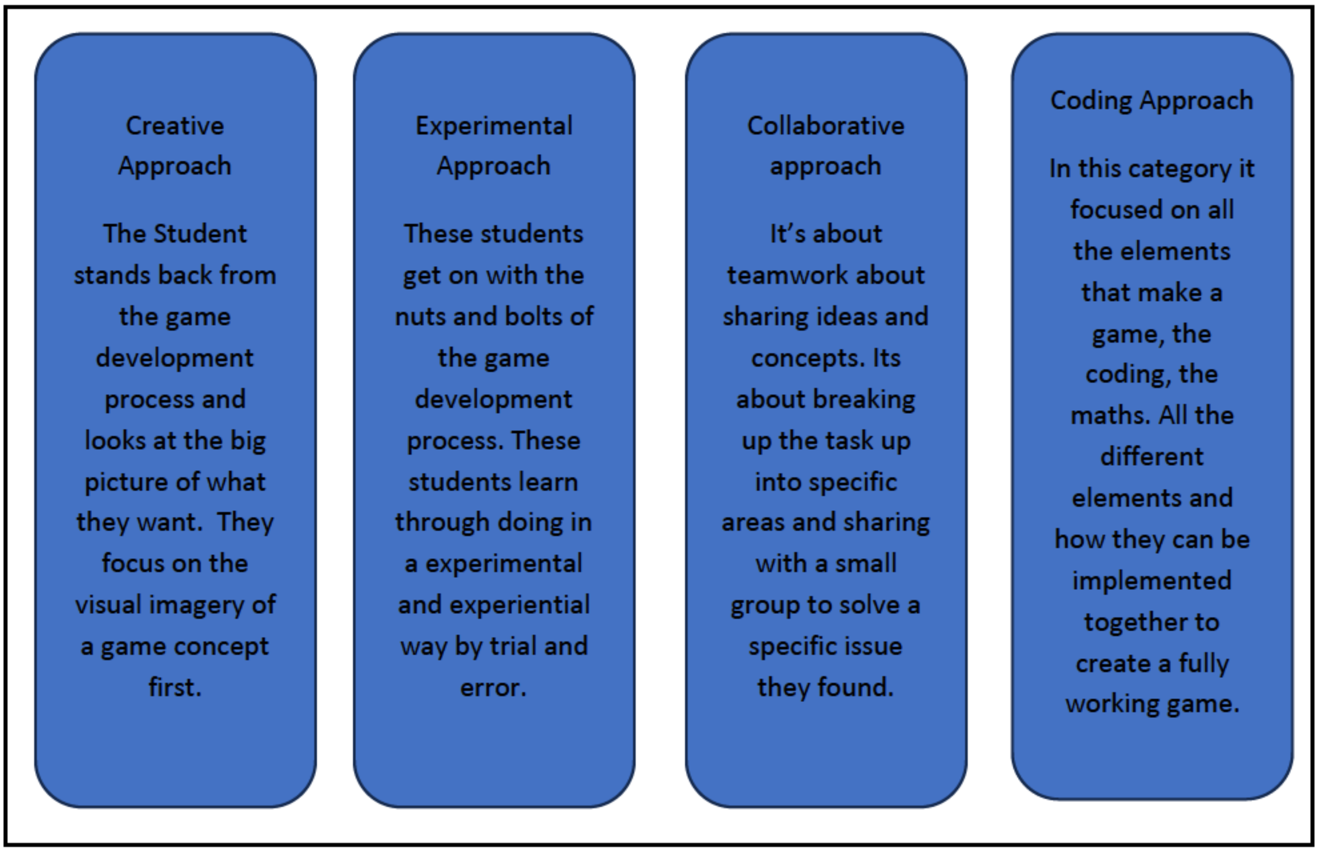

Fig 15: Showing categories of description.

Figure 15 gives a good summary of each of the categories of description from the least developed (creative) through to the most developed category which was the coding category.

7.4.3.1 Creative Approach

Hierarchically this category of description was the lowest. It was the creative inspiration the students had first, even before they started to make the game. The student stands back from the game development process and looks at the big picture of what they want. They look at the visual imagery they want and how it could be applied. This comes from games they have played and the visual themes they wish to apply. They focus on creating story boards, background stories and do the artwork for the game.

The 3 students that described attributes of this category where students 1,7 and 26

"I also got my inspiration from a dream I had. I dreamed I was in a mossy like jungle like place and that I also include that in the game. From BioShock I got the sea creatures from there. Also, the water elements from BioShock I got and used in my game. I loved animating the sprites and spending time developing them and getting to look and feel as I wanted. Really enjoyed that process."
(Student 1).

This student was making the game with a 'BioShock' theme. This student, when making the card game, their focus was all on the artwork and the creative inspiration of what the game should look like. They looked at the deck of cards from this perspective.

"I like the visual aspects, relating the Nintendo universe to this card game, I like that. So the sprites... I really like creating all the different visuals with inspiration from the Nintendo universe…"
(Student 26).

When these students made their games, they referred to this picture constantly. From the interviews it can be seen some students who stay in the creative category can have a rigid view of the picture, and, as they are designing it, if they don't get a game that matches this internal picture, they can struggle and get frustrated, get stuck and not move forward. Bruce in her research also discusses this (see section 8.4.1).

"I found the concept art easy. The designing easy. The coding side of things and the maths are the things I found hard. It was very challenging".

(Student 1)

This student looked at the game development process as a part of a big picture. This also means that the maths element within the card game must fit into this picture.

These students tended not to like the coding elements and for the most part, struggled with it.

From the results, Student 1 fits in the Creative Approach category. When *asked "Are you quite arty and creative?"* they answered, "*Yes I like to think I am. The King, Queen and Jack, they were fun to do the art for them."* When asked about coding they answered, *"I think I was kind of overwhelmed by the card game because there was a lot of coding which I really don't know how to do. I was very relieved at the end because I finally got it done, I more or less got the card game working."*

The role maths played for this student was that they admitted "The coding side of things and the maths are the things I found hard. It was very challenging." (Student 1).

Student 1 focused on and enjoyed the creative elements but did not enjoy the coding aspect. All the students started with a 'big picture' of what the game should look like, but student 1 stayed there and rigidly stuck with this fixed picture. They were also less independent and sometimes didn't ask for help.

Appendix 8 shows in more detail about the game created by student 1.

Student 7 answered: *"I was really excited at first because I thought this is what I wanted to do. Like at first the course was like writing and stuff so I kind of wanted to get into doing the making games and the drawing aspects. I really wanted to get into that because that's what I did the computer science back at school. But my High School teacher said he was more graphics based which is what I wanted to do and I was really interested in it at that time. But it wasn't, so I gave my hopes up back then and that really annoyed me so I studied computer science for two years and that didn't change so I didn't really enjoy that at all."*

7.4.3.2 Experimental Approach

In this category it's all about how the student approaches the game creation process. They start with a creative picture as above but that is not their only focus. These students eventually get on with the nuts and bolts of the game's development process. These students learn through doing, in an experimental learning approach. They learn by doing. Kolb describes how knowledge is gained first-hand, instead of hearing or reading about others' experiences. The game they have can be different from their initial ideas but is generally what they first visualized. These students have a go then when they get stuck they ask for help. Some of these students played the card game and discussed the mechanics with the lecturer.

Students 3,6 and 26 expressed attributes of this category.

"I fiddled about with it until I got it right" (student 3).

This student initially had an experimental learning approach to the game creation process. They didn't just have a creative picture but were able to progress and figure thing out.

"I like the visual aspects relating the Nintendo universe to this card game, I like that. So the sprite... I really like creating all the different visuals with inspiration from the Nintendo universe and I thought that that turned out well. I sort of kinda like doing the coding and stuff and seen how it all work together. I have an analytical mind so I enjoyed that; seeing how things piece together and work and all that. So yeah it was quite fun."
(Student 26).

This student (26) had a creative picture, but they are not just creative. This student was able to experiment and figure things out. Notice how they enjoyed putting it all together, that was where their passion was. The students were actively reflecting on their personal learning journey. This breaks away from the tradition academic process of gaining dry subject knowledge. This approach is about an iterative cycle of learning a skill then applying it.

"Yes, I watched your videos I know. So I went online to look at the Game Maker docs. So like if I had something wrong within the game I then type that in and then it

would show what that code would have a looked like and is supposed to have. So I could correct any mistakes I had and make it work as best it could"
(student 26)

Here we can see this student is using technology (a YouTube video) to try to solve a problem they have and adapt some code for their use, they were experimenting with code in affect.

"It's going to be quite hard because I don't know anything about coding and that involves a lot of coding and work and writing math stuff, which is going to be confusing". Then they added "I'll be able to get my head around it by watching vids and fiddling with it and get a working game."

(student 6)

This student was interviewed as they were completing the card game. They could see problems with making the card game but had watched some videos that explained some of the process of game development and they felt they could figure out any problems they had to complete the game.

"If I had watched your videos, I would have had to start all over again and I didn't want to do that. I think I went the way I did because I wanted to really learn the coding and any want to just copy and paste what you are doing, I wanted to take bits from this website that I had seen and use the bits I understood."

(student 3)

When asked about the games development process they expressed a desire not just to copy and paste some code elements from a video I provided about making the card game. They wanted to learn to experiment with the code to get a card game working. This is backed up with a further comment they volunteered.

"So, I did all the basic sprites and backgrounds, and I did the global variables first and then I looked at the videos. I looked at your videos, but I had already started looking at the other ones and it didn't make sense with what I've already done."
(student 3).

7.4.3.3 Collaborative Approach

This category is about working with others to share ideas and help each other create the game. This category is higher in hierarchy than experimental. One significant difference is that students work with others. It's about teamwork, communication and about breaking the task up with others and putting focus on specific areas then sharing with a small group on how they solved a particular games design issue they found. They tend not to seek help from the lecturer. They support each other and rarely ask for help directly. These students choose to work together with others after asking lecturer. They work best with their friends and with online resources.

It was observed that these students played the card game with each other to figure out the game mechanics, they did this as they developed the game.

Two students expressed attributes from this category. Students 3 and 7 worked at some part to help/support in team work to solve the problems in the games design process with each other.

"I was looking at some tutorials online and someone did do a card game and the majority was a lot like that, so I took quite a lot of that and adapted it and then me and (student 2) and (student 26) worked together to help each other to figure out the bits that weren't explained. The majority of it was we had to change. I had to change all the positions and change it from two people to four people." (Student 3)

This is a Collaborative expression; the students watched a tutorial and then helped each other figure out how to make a game. When interviewed student 2 did not mention working with other students. Although student 2 was mentioned by student 3, student 2 didn't express that he worked with others during the games design process.

When asked about how they worked with the others they answered, "Well we kind of helped each other we literally do it together because we all had different ideas." (student 3)

In this student 3 reflects on the fact that although they worked together their creative pictures differed from each other.

When asked "Did you talk to others or did you figure it out by yourself"

"I did get some inspiration from the 80s films we'd been looking at and all the 80s era. That's where I got most of it from, but I did talk to my friends with stuff like what shall I do with this style with that style. At first it was just a 'I will do this' and I did, then I came up with another idea and then I thought that doesn't really fit the brief so I thought to myself I will stick with my main idea because usually I would create another idea and never get it done. That's what I usually do. Instead, I've just stuck with the initial idea and it worked out really well." (student 7)

Student 7 had a creative picture of the card game but was flexible and this idea changed as the game evolved. They experimented with some ideas and discussed and worked with other collaborative students and eventually returned to the original concept.

When asked "So how did you approach the learning of the card game?"

"I did look on YouTube. I also asked my friend (student 26). They helped me a lot. She's smart. She looks at lots of YouTube channels as well and gets a lot of information/inspiration from there". (student 7)

They got information about how to make the card game from student 26 who had watched more YouTube videos.

When interviewed, student 26 didn't mention working with other students. It's clear they were asked for help but didn't express themselves as a collaborative worker.

7.4.3.4 Coding Approach

In this category it's more focused on the coding aspect of the game; how the mechanics works within the game. The student looks at how things work in a game and how to implement them. It's hieratically linked to experimental learning but with the focus on coding. It also is linked with how the students implements the maths side of the game. These are independent students and rarely ask for support. They may have a picture of what they want but what they create can be very different from their initial ideas. One student was observed playing an online version of the card game to better understand the mechanics and how to present it as a computer game.

Student 2 and student 4 are part of this category.

Now looking at student 2 who firmly fits in the Coding Approach category. They had a 'big picture' as well but developed this and experimented with some ideas but then eventually enjoyed and focused on the coding side of things. When asked about how they made the game they answered. *"So, to start with I got the sprites of the objects out the way, so I created those then I did some research, the statements, the functions, how scripting works and then after that created it piecemeal".*

When student 2 was asked about making the game:

"So for the card game I would say it's because they got 52 cards and putting them randomly in a deck so that they can go in each person's hands from any suit any number and then I display the total on the screen so you have to add up what the player has in their hand and display as that number so they got a 5 and 7 you can get 12 that's quite a lot of maths and then there's the chips you got to display them in the top corner and then if you click the one that says 100 you are the 100 and then if you win you give that back to yourself or if you lose you obviously lose that". (student 2)

Student 2 also said, *"So to start with I got the sprites of the objects out the way so I created those then I did some research, the statements, the functions, how scripting works and then after that, created it piecemeal changing it as I progressed."*
They had a picture but were flexible with it, they used creative software at first but then moved onto the coding tools. They had some support and structure at first but then came up with their own structure and ideas.

The game idea is not as fixed, *"changing it as I progressed".* It changes as the student makes the game depending on how their research went. They didn't get fixated on the creative aspect of the game, they "*got the sprites of the objects out the way*" so they could focus on the game making process instead. This is made clear when they further commented on making the card game.

"So for the card game I would say it's because they got 52 cards and putting them randomly in a deck so that they can go in each person's hands from any suit any number and then I display the total on the screen so you have to add up what the player has in their hand and display as that number so they got a 5 and 7 you can get 12 that's quite a lot of maths and then there's the chips you got to display them in the top corner and then if you click the one that says 100 you are the 100 and then if you win you give that back to yourself or if you lose you obviously lose that" (Student 2)

Student 2 can clearly be seen focusing on making the card game, looking at all mechanics of this game.

"I learned a lot about coding and scripts in the game, more about implementing scripts into the game itself more than anything else. Whilst making this game I learnt a lot of new code" (Student 4)

"The game was surprisingly easier than expected. With more maths and code involved I expected it to be much more challenging. I began to actually enjoy the coding at some level as it can make the game very cool." (Student 4)

These are the categories of description found in the students doing both games. It must be noticed that all students did both games; the card and space invaders games. The maths tests were after the sample had made the first game which was halfway through the academic year. These categories are logically separate but hieratically linked. These categories are the perceived focuses the students took. Another way of looking at them is the student's passion or focus. Some students had more of passion for the creative point of view, some focused on experimenting while creating the game (trial and error), some like working in a team and some connected with the coding more. The 13 students all fitted in one or more of these categories. Most just had one focus. These categories can all develop from each other. The least evolved categories been Creative, then the Experimental one is next which has elements of the creative. The Collaborative is even more involved and had elements of the two previous categories. The most evolved is the Coding that has elements of all the categories with it.

Appendix 8 shows in more detail about the game created by student 4.

7.4.4 Dimensions of variance

The categories of description are about the students focus or what they did and how they experienced it. The next step is about the dimension of variance, on how a student experience varied. Four key aspects that varied when looking at the scripts were (1) the role that technology had with a student, (2) the role a lecturer had, as in the interaction and level of communication/support the student needed or engaged with, (3) the role maths has and (4) the role the game has. How do these vary from category to category?

7.4.4.1 Role of the Lecturer

The lecturer is a part of the environment of the game development cycle. The role the lecturer plays varies from student to student. In the beginning the lecturer introduces the game concept and some game ideas and even demos game play using a real card game and a video game.

Creative approach students. These need more direction and support from the lecturer. The student's big picture about what the game looks like can be quite rigid and can prevent them from developing the game sometimes. They can get stuck and find the coding and card game design aspect a challenge.

Experimental approach have a creative picture but are more focused on experimentation and on experiencing the process of making the game. They play about with game mechanics and try things out. They prefer to try first then ask questions later. The lecturer does not need to support them as much as in the creative category.

Collaborative approach are even more independently minded and the lecturer may not support this group of students who are working collaboratively. It must be pointed out these students are all individually making their own game but work collaboratively to figure out the mechanics of the game design.

Coding approach student are the most independent and tend to work on their own with a very fluid design that changes constantly as they develop as coders and as the game develops. They rarely need support from a lecturer.

7.4.4.2 Role of the Technology

This is how the students engage with the different types of technology. The scope of technology is also looked at. The way they use it and the amount they use it.

Creative approach students focus on technology that helps them develop their inner picture of what the game should look like. Such as Photoshop / sprite creator software etc. With the game engine itself, (GameMaker in this instance), they focus on the sprites and animation more. The time they spend on the creative technology is significant.

Experimental approach & **Collaborative** approach students use GameMaker from the get-go. They try things out first then put sprites in the coding. They refer to games design tutorials and in the case of the **collaborative** approach, try different approaches and then discuss the outcome. The **collaborative** students also discuss the technologies they are using (for example forums or YouTubes they have seen) and share this.

Coding approach students use GameMaker from the get-go but focus on the coding aspect part of the engine (GM Script, which is like c# coding). They read forums and research online how to do certain things and constantly improving their code. The **technology** is the forums / YouTubes etc. that help them figure out 'how to' do various aspects within their game design process. They are however focusing on how to make a card game, how to code the maths aspects, not just coding for the sake of coding.

7.4.4.3 Role of the Game idea

In the beginning the students were given the brief of making a card game. From this brief the students came up with an initial game idea. This game idea was what shaped the game they eventually created. For some students this game idea was quite fluid and changed, for others it was a rigid idea that did not change.

Creative approach – with these students the game idea was the big picture they saw. It seemed to be rigidly adhered to even if it was not practically implementable. These students can be perfectionists and need help from the lecturer to soften this rigid idea into a more workable game concept.

Experimental approach and Collaborative approach students had the big picture and do their best to adhere to it but were more flexible in their approach than the creative approach students. The games they created looked like their big picture with some differences.

The **Collaborative** approach student's games may look similar in look and feel as they have worked together but have created separate games, with some differences.

The **Coding** approach students had a big picture and started with this but as they developed their game, they evolved it and improved it. So the final game was better than or very different from the initial idea. They were the most fully functioning games of all the games produced. They had the most fluid game ideas.

7.4.4.4 Role of maths / cards

The students were making a card game, a game with a maths aspect. It was not discussed as a maths aspect (part of the **stealth approach** mentioned previously). It was discussed in connection to the making of a game. The students have the 'card game' within their original game idea. The difference is in how they see how to develop and implement this concept of a card game into an actual computer game.

Creative approach students had a card game idea, they may have played a card game like 'hearthstone' or played a physical card game. These students tended to struggle implementing the card game concept. They did get stuck and needed support.

Experimental approach students had a card game idea and picture but tried experimenting with different ideas until they found something that worked. They played the real game with others as well.

Collaborative approach students had a card game idea and picture but tried experimenting with different ideas as a group until they found something that worked. They shared this with their small group and tended to go with the best results. One issue is that once a solution was found they all tended to use this one, with modifications.

Coding approach students - these independent students had a picture and did research on how to implement and code that. They looked on forums and experimented with other code samples. When they found something that worked, they implemented it. They were not afraid to play about with different code and look online for sample code.

7.5 Outcome Space.

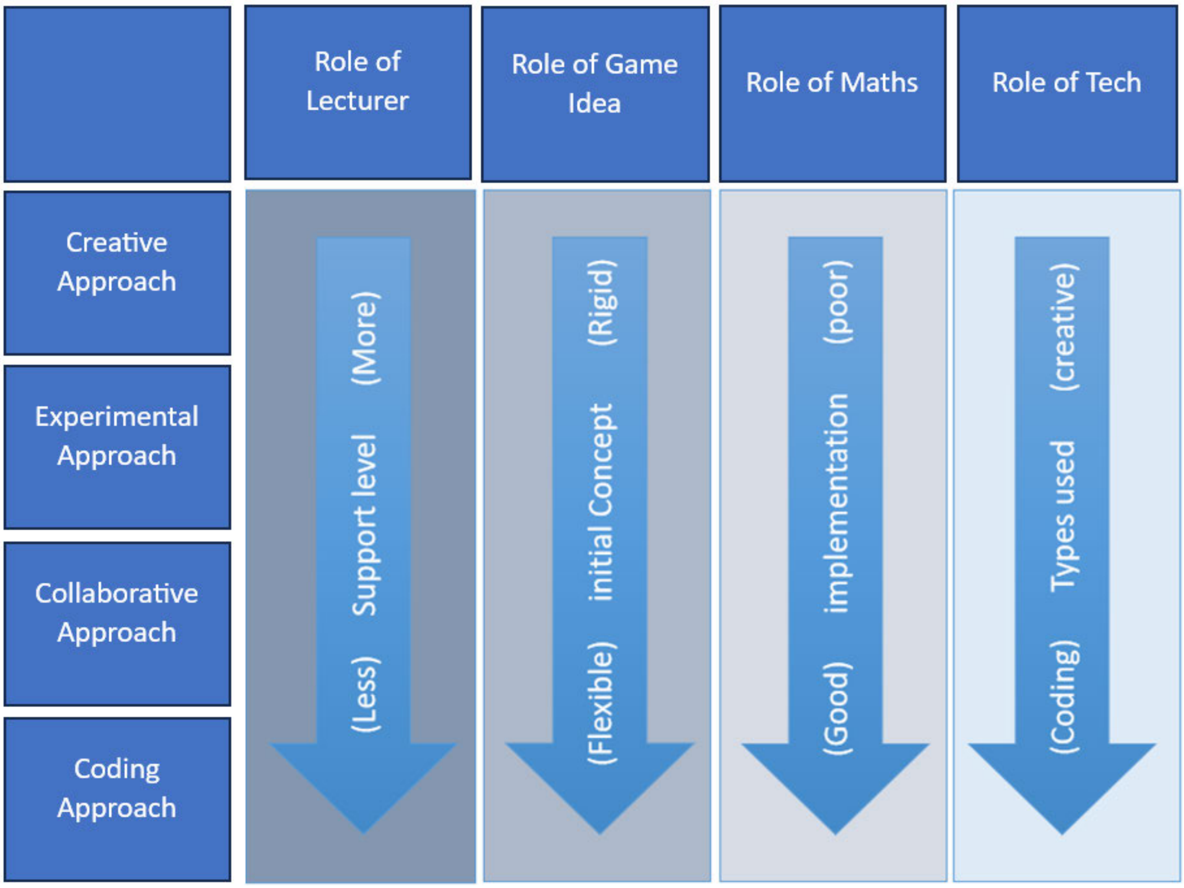

Fig 16: Outcome space

The results from the phenomenographical study creates a picture in the form of an outcome space (fig 16) which shows the different approaches (categories) the students where part of and how this links with the varies roles (dimension of variance). Such as the role that maths, technology and the game idea took for them. To elaborate further students who was part of the coding approach (student 2 and 4) needed less support from the lecturer and had a more flexible view of the initial creative game concept. They had generally a better understanding of game implementation and maths as well. As contrasted with students who identified with the creative approach (students 1,7 and 26) some of whom had a more rigid mindset about the initial creative game concept, these students generally needed more support from the lecturer. Some had a poor understanding of game implementation and the maths aspect of the game as well. This outcome space is a picture of the way the students experienced learning within the games design process. This maps to the concept of the serendipitous learning environment first discussed in section 4.7. This is further elaborated in the Discussion chapter section 8.2.4.

7.6 Summary of results

This chapter showed the results from the phenomenographical data analysis and the RCT data analysis. The phenomenographical analysis discovered four hierarchically linked categories of description of experiences that the students had when making the card game. The first category was Creative, which was where the student looked at the visual image of the game they were creating. It was about the picture a student had of what the game would be. The next category is the Experimental approach category. Students that engaged with this category experimented with different aspects. They learned by making mistakes and learning from them. The next more evolved category is the Collaborative approach one. In this category the students worked with others to share ideas or get help. The final one is Coding. The student used a variety of technology tools to help them create a game and their game was not fixed to how they first saw it during the initial stages of the game's development process.

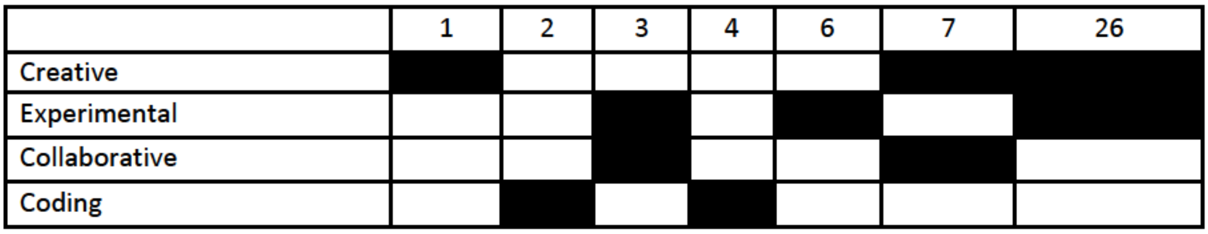

Fig 17: This diagram shows students (the columns) with the categories that they were part of (the rows). Also, this shows which students crossed multiple categories (multiple areas shaded black in columns).

The RCT was seen as important but supporting the phenomenographical data. Analysing the data, the mean for the experimental group was 13% compared to 3% for the control group. This is a 10% increase from control to experiment group. The Discussion chapter will discuss the relevance of this data and also how the phenomenographical data links with the RCT data. All this data is further reflected on and discussed in the following chapter.

8. DISCUSSION

8.1 Introduction

This thesis was to investigate the hypothesis that student learn maths whilst making a computer game with a maths element embedded within it. To research this hypothesis, two distinct research questions arose which led to two parallel research studies. This chapter presents a discussion on the results of the quantitative and the qualitative studies presented in the previous results chapter, including how these results compare to similar studies that have been done. This research study encompassed a mixed quantitative and qualitative aspects to address the research questions the study sought to investigate. This chapter also discusses the factors that impacted this study such as the technology used, the maths subject itself, the pedagogies used, and the serendipitous learning environment within the culture of an FE college. This chapter reflects on the roles played by the teachers and the student and compares the findings to other comparable studies that used phenomenography. This chapter also discusses how this research can contribute to game-based learning of maths education in the future.

8.2 Summary of results

The results of this study show the different roles which students and teachers played in this research. The phenomenography gives the qualitative picture of what students experienced during the Games Design process with the RCT seen as supporting this. This is shown when the data is disentangled and when the RCT and the phenomenographical data is linked coherently to give a 'big picture' of how the students experiences of engaging with maths within a games design concept and students' skill of maths through the RCT measurement.

8.2.1 RCT summary

When analysing the data, the mean for experimental group was 13% compared to 3% for the control group. This means a 10% increase from control to experiment group, which is a significant increase of maths skills learned for the experimental group versus how much maths was learned in the control group. Also, a t-test to check the validity of the data shows that the null hypothesis holds with the datum given. T-Test result 0.003553 < 0.05 so the null hypothesis holds. This shows that the 10% maths increase by the experimental group statically holds true. This data suggests that that the experimental group learned more maths than the control group. This then supports the Phenomenographic approach which took place in parallel to this study.

8.2.2 Phenomenographical summary

This study gave a deeper dive into students' experiences of learning maths through making a computer game using a phenomenographical quantitative process. In summary, the perceived learning approaches the students took are the four categories of description. The lowest is 'creative approach', the being the least developed approach taken. 'Coding approach' is the most developed approach. Each category is hierarchically linked with the other categories (see results chapter section 7.4.3)

Creative Approach (lowest and least developed)	[redacted] be rigid with this imagery. [redacted]
Experimental Approach	[redacted] *the problems they have in a trial-and-error approach.* [redacted]
Collaborative Approach	[redacted]
Coding Approach (highest and most developed	They use technology well and are more self-motivated and determined to push through problems. *"So to start with I got the sprites of the objects out the way so I created those then I did some research" (Student 2)*

Fig 18: Summary of the 4 categories of description found in this study.

The Categories are 'how' a student experienced the roles and 'what' the various aspects are that impact the students within these categories.

Creative Approach - students 1,7 and 26 showed attributes that linked with this category. Student 1 stayed in the approach but students 7 and 26 both showed attributes from other categories. This shows that student 7 and 26 both managed to progress beyond a fixed visual image. The Role of the Lecturer in this category is more supportive of the students in trying to get them to move from this rigid image. The Role of the Technology in this category is more creative in nature, more focused on game art. The Role of the Game Idea is the initial creative inspiration of the game and how it feels. The Role of Maths in this approach is distant, the student is not considering it.

Experimental Approach - students 3,6 and 26 expressed attributes of this category. These three students experimented with the games design process and were able to figure it out as they progressed. Student 26 showed a Creative approach but also could experiment, they didn't however work with other students. Student 3 did Experiment and try to figure out what to do but also has Collaborative attributes. Student 6 showed just Experimental attributes and didn't work with others. The Role of Lecturer in this category helps students at first then students can experiment themselves. Some structure is given by the lecturer at first but then the students then move on with their own concepts later. The Role of the Technology in this category is the game engine (GameMaker). It's about the nuts and bolts of making the game. The Role of the Game Idea starts with initial ideas but is adaptable and changes as the students experiments. The Role of Maths in this approach is less distant than the Creative approach but the student is still not considering it.

Collaborative Approach. Students 3 and 7 both showed attributes from other categories but neither have Coding approach attributes. These students work well with others and often figure things out together. The Role of Lecturer in this category is more coaching based with some support but the students turn mainly to each other for support. The Role of the Technology in this category is the game engine (GameMaker) and usually a 'YouTube' that shows how to do something. They watch together and help each other understand it. The Role of the Game Idea starts with initial ideas but is more adaptable and changes as the students experiments. The Role of Maths in this approach is that it is now discussed with others as they try to figure out how the card game works.

Coding Approach - Student 2 and student 4 are part of this category. These two students just exhibit Coding approach aspects. This means that they like to learn the mechanics of making the game and the scripting used to make the card game. They used forums and 'YouTubes' the same as Collaborative but don't look to others for support. They are independent workers. The Role of Lecturer in this category is more coaching based, with little if any support. The Role of the Technology in this category is the game engine (GameMaker) and usually a 'YouTube' that shows how to do it and forums etc for help. The Role of the Game Idea starts with initial ideas but is very adaptable and the final game can be very different from the initial concept. The Role of Maths in this approach is more central to them. They were more focused on the mechanics of a card game.

The results from the phenomenography create a picture in the form of an outcome space (section 7.5) which shows the different learning approaches the students took and the role that maths, technology and game idea took. This and the role teacher all map together.

8.2.3 Phenomenographical outcomes reflection and summary

The second research question for this research was RQ2 "How do students experience learning maths through making a computer game?" The students experienced the Games Design process with the maths element within in it in four qualitative ways, which encapsulate the students' Games Design making experience. On reflection of this and to summarise it can be argued that the more a student engaged with the Games Design process and got immersed (visualised in Fig 18 above) within it then the more the student learned. A student who was 'coding focused' used technology well and was flexible with their Games Design process and figured out the maths aspects tended to learn maths better than student who didn't.

8.2.4 Reflection on Phenomenography and RCT results

This is a mixed method research which includes aspects of qualitative (phenomenography) and quantitative analysis (RCT). As they stand neither analysis on its own gives a clear picture. Only when the data is linked can a better picture be gained. As discussed in the methodology chapter (section 5.3) the phenomenographical approach was seen as the more important aspect (links with RQ2) than the RCT (which links with RQ1). Phenomenography only requires a small sample size (n=7) and the RCT (n=30). These are small sizes however it can be argued that this produced a sufficient data saturation to give reasonable understanding of the various aspects of the phenomenon in question, which was students experiencing learning maths and how that impacted on their maths skills (RQ1 and RQ2).

Its, important to link this data now to give a more coherent picture. In the results chapter the RCT data and Phenomenographical data was kept separate. The phenomenographical data needs now to be mapped to the RCT data.

	1	2	3	4	6	7	26
Creative	■					■	■
Experimental			■		■		■
Collaborative			■			■	
Coding		■		■			
% increase (Pre / post)	-5	19	14	20	14	5	12

Fig 19 Showing the mapping of RCT results to categories of descriptions.

Fig 19 shows how some students exhibited characteristics of more than one category of description. The column indicates the student's number, and the rows the categories of description and the percentage increase in maths score pre to post games design process. Elements filled in black indicate that a student exhibits characteristics of that category, with some students being part of multiple categories.

Within the Phenomenographical categories the Creative Approach Students 1,7 & 26 were seen and discussed (see section 7.4.3.1). They got RCT results of -5% (student 1) and 5% (student 7) and 12% (student 26) respectively. This is a wide range of results from this cohort. Student 1 experienced the creative side of the game development process as easy and the other aspects of the game creation challenging. "I found the concept art easy. The designing easy. The coding side of things and the maths are the things I found hard. It was very challenging" (Student 1). They clearly struggled and didn't experiment or work with others to resolve their issues. The RCT results of –5% change from initial maths test to final maths tests shows that because of focussing on just relative aspects of the games design and clearly struggling with the mechanics of making the game which they found 'very challenging' it impacted negatively on their maths test results.

If we compare this to student 7 who was also creative, they struggled but turned to another for help. *"I did look on YouTube I also asked my friend (student 26) she helped me a lot she's smart she looks at lots of YouTube channels as well and gets a lot of information inspiration from there"* (student 7). The RCT results were a 5% change, the simple choice of looking for support from another participant within the study had a positive effect on their learning.

The final participant of this category, student 26 used both creative and experimental approaches. They had a creative start to the game development process and had "visual aspects relating the Nintendo universe to this card game" (student 26). This participant also then experimented and looked at online resources to figure out the problem. When asked what resource they used they answered "Yes, I watched your videos I know. So I went online to look at the GameMaker docs so like if I had something wrong within the game I then type that in and then it would show what that code would have a looked like and is supposed to have, so I could correct any mistakes I had and make it work as best it could" (student 26). This student when they got stuck went online and researched the problem and experimented with the mechanics of the game to get it working. The RCT of 12% for student 26 shows that maths learning did take place.

The Experimental Approach category participants were identified as students 3,6 and 26 (see section 7.4.3.2). They got RCT results of 14% and 14% and 12% respectively which indicates that maths learning took place for all these students. Student 26 is discussed above.

Student 3 was identified as experimental. When asked about the game development process they replied "I fiddled about with it until I got it right" (student 3). They didn't

just use experimental language. They further replied as part of the conversation about games development; *"I was looking at some tutorials online and someone did do a card game and the majority was a lot like that, so I took quite a lot of that and adapted it and then me and (student 2) and (student 26) worked together to help each other to figure out the bits that weren't explained. The majority of it was we had to change. I had to change all the positions and change it from two people to four people*." (Student 3)
This shows that student 3 was collaborative as well and worked with two others to figure a problem out. Student 6 was interviewed as they were completing the game and when asked about the game development process they replied. "it's going to be quite hard because I don't know anything about coding and that involves a lot of coding and work and writing math stuff, which is going to be confusing". Then they added ""I'll be able to get my head around it by watching vids and fiddling with it and get a working game." (student 6) They had been trying to develop the game but had struggled but could see that they could get it working by watching videos and fiddling with it. This student had missed some sessions and was catching up with the game making process. Both student 3 and 6 got 14% RCT results which indicates significant maths learning took place. Student 26 discussed earlier got 12%.

The Collaborative Approach category students 3 and 7 (see section 7.4.3.3) got RCT results of 14% and 5% respectively. Student 3 is discussed in detail above. When questioned about the game development process student 7 replied. "I did look on YouTube I also asked my friend (student 26) they helped me a lot. She's smart. She looks at lots of YouTube channels as well and gets a lot of information inspiration from there" (student 7). This student got help from student 26 to both understand some content on YouTube and how to implement it within their game.

The Coding Approach - Students 2 and 4 (see section 7.4.3.4) got RCT results of 19% and 20%. Student 2 when asked about the creative aspects of the game replied "So, to start with I got the sprites of the objects out the way, so I created those then I did some research, the statements, the functions, how scripting works and then after that created it piecemeal". They didn't have a creative view of the game, in-fact their focus is on the mechanics of the game. Further to this student 4 replied when asked about making the game that "The game was surprisingly easier than expected. With more maths and code involved I expected it to be much more challenging. I began to actually enjoy the coding at some level as it can make the game very cool." Student 4 enjoyed the experience this was a surprise to them as they expected it to be a hard development process. Student 2 also said that they recognised that the game had "quite a lot of maths" (see 7.4.3.4 Coding Approach) in it.

At this point it's useful to discuss student 26 who although they described themselves as creative and experimental was mentioned by student 7. Student 7 described working collaboratively with them, but student 26 didn't mention working with others. It can be inferred that student 26 helped student 7 but didn't learn with student 7. The same can said for student 2 who was also mentioned by student 7. Student 2 didn't mention working with student 7 in their discussions.

As can be seen, these students all experienced the games design process in a variety of qualitative ways. This all took place within the serendipitous learning environment.

8.3 Reflection on factors that impacted the study

This study took place within the context of a FE college, which has limited funding (see chapter two), but however presents some advantages. So compared to a student doing 'A' Levels they have to do 3 academic subjects. For FE they do one course of study (that is equivalent to 3 'A' Academic Levels). This means that students are naturally more motivated to do a course they choose than doing a several courses that they had some they may have no choice with. Also as discussed in the FE and Math chapter, the culture of FE is more relaxed than at schools, where the students can come and go and attend only when they have lessons. The more casual dress code (no school uniforms FE and maths section 2.7.1) and atmosphere (see serendipitous learning environment section 7.7.2) all had an impact on this study.

8.3.1 Main Themes

Three main themes that became paramount in this research focus on the roles that each of these aspects played in the enhancement of maths learning: (1) the serious Games Design process, (2) the maths element within the design process, and (3) serendipitous learning and a stealth approach. All these themes link in this research and are interconnected. The connection may not seem apparent at first but in simple terms the maths element is embedded within the serious games design process in a stealth approach which enables or facilitates the serendipitous learning to take place.

As well as these three these themes, the roles of the lecturer and student are discussed and how and why they change within each theme.

The Games Design course used immersive technologies in the form of game engines, online software, and graphic art software packages. Students are intrinsically motivated to engage with these Immersive technologies (as discussed in chapter three) they capture their attention of whoever uses them (Djaouti et al 2015). This adds a further motivation to students doing the course. Students are engaged with the game development and are invested in this process. The role of the student is more self-directed; they are more invested in their own learning which is intrinsically motivated (see chapter 3). However, this mechanism of game-based learning is reliant on the lecturer enabling this process and how the student responds to this. This leads to the role the lecturer plays in this process. In traditional teaching practice the teaching is lecturer/teacher led (see chapter 3) with the lecturer providing the information and the student learning is a structured step by step way. As already stated, when it comes to engaging with immersive technologies (section 3.3), the students are more intrinsically motivated. The step-by-step approach of a traditional approach (as discussed earlier see section 3.6.1.1) was felt to restrict the student's creative process. This facilitated a more modern approach which is game-based learning and also implementing a more "humanistic theory based" teaching style. Where the student is not just seen by the lecturer as someone to teach but as an individual with needs and expectations, one of which is to learn Games Design. Doppelt et al. (2008) when discussing DBL which is closely related to GBL argue that the learning is an "active process" and "puts the students at the centre of the learning process" (2008:23). Further Doppelt et al. (2008:23) state that this approach "changes the teacher's role from that of lecturer to the roles of tutor, guide, and partner in the learning process" . The lecturer acted as a facilitator of learning and as a mentor, coach. Not just as an information source.

The main theme is maths (see sections 2.8, 2.9 and 4.6), specifically the maths elements with the game the student is making. It is one of the focuses of this study. Pouyamanesh and Firoozeh (2013) argue, some students have a "fear of failure" when they do maths. Another element is apathy towards maths as a whole. Kislenko et al. (2007) argue that students know maths is important but are "bored in the maths lessons". From this observation it can be argued that some students do not want to learn maths and have little motivation to learn maths. This led to hiding the maths element within the serious games technology. The students when engaging with the serious games' technologies are intrinsically motivated to overcome an apparent fear of maths / apathy towards maths to engage with maths in a more meaningful way than if they engaged directly via a traditional teacher-centred classroom approach. This use of serious games was one of the areas that impacted on the students learning maths. The role of the student is to make a game. They are focused on the games design not the hidden maths element. The role of the lecturer is to be a facilitator of learning, to mentor and to help when needed not to direct the games design process.

One of the unusual aspects of this research study was how serendipitous learning and stealth approach was used. One of the issues highlighted in students learning maths is a "fear of failure" (Pouyamanesh and Firoozeh 2013), as well as students not been motivated to engage with maths. In the study, the maths element was never overtly discussed in the class sessions, so the students were not directly aware of it. It is in fact as much as possible hidden from the student. The students were making games with a maths element and were given a formal assessment; however, the focus (assessment and students) was always on the game not the maths. The maths is seen only as a secondary aspect by the lecturer during sessions. In these students led sessions the students made the maths aspects as part of a game. The Phenomenographical data shows how students creatively looked at and how they made the maths element for their games. This stealth approach was seen as another factor in helping the students engage with maths in a more meaningful way. In this environment, they were intrinsically motivated to create games with a maths element within it and not be directed to a potential "fear" of maths. "When embedded assessments are so seamlessly woven into the fabric of the learning environment that they are virtually invisible, we call this stealth assessment" (Shute, Iskandaria and Oktay 2010). This research does not use stealth assessment as Shute et al uses. There is through an overarching stealth approach that is used for the teaching and assessment of students engaged with this research. In summary the stealth approach is an overarching approach that enables the embedding maths learning within a learning activity that is focusing on game design as the explicit context.

The serendipitous learning was observed from feedback from one-to-one interviews after they had made the games. In the results chapter (section 7.4.3.4), for example, Student 4 commented "maths and code involved I expected it to be much more challenging" and student 2 said, "I did some research on statements" and student 3 talked about "I fiddled about with it until I got it right".

8.3.2 Serendipitous learning environment

All these themes come together in a "serendipitous learning environment" (section 4.7). As discussed in the Serious Games and Learning chapter, most teaching and learning is teacher-led. This is a structured and organised approach in which students are taught in a step-by-step way. Within this study, the teaching and learning that took place was much less structured and it was student-led. In the beginning of the Games Design teaching process, the students are given a basic tool kit of knowledge to make a game. Once this has finished the students are given "free reign" to create the game any way they please. The lecturer is simply acting as a guide to the students.

This is seen as a key area that differentiates this research from other research done in this field. This "serendipitous learning environment" relies on the following aspects.

The lecturer / teacher needs to set up a teaching environment that facilitates a student-led approach and be able to release the reigns of teaching to the students in a step-by-step way. The students use an immersive technology (games design) in which they are free to explore and self-learn. A stealth approach of introducing maths aspect into a game the student makes. This concept is also discussed within

Bruce et al (2004) research where she reflects on how learning experience can be enhanced by teachers design learning experiences for students (Bruce et al 2004).

Also, as part of how this was measured from a phenomenographical standpoint a stealth approach was used to question the students about this experience. Thought this last part is not part of the serendipitous learning environment. From phenomenographical data those that do well are those that embrace it better (see section 7.4.3.4).

The FE culture (see FE Culture chapter) helps to facilitate this because the students are encouraged to think for themselves. Another factor that helps this is the use of serious games technologies (see Serious Games chapter and above) which require the student to explore and experiment.

In summary serendipitous learning environment has these elements / attributes: -

- Stealth approach is used to embed the maths element (Shute and Ke 2012; Shute, Iskandaria and Oktay 2010).
- Design based learning approach is used (Doppelt et al 2008; Barron and Darling-Hammond 2008; Arnab et al 2019).
- Collaborative based learning is used, some students work in teams, some don't but the teaching style allows for this (Panitz 1999)
- Humanism teaching theory, students are seen as not just learners but as a whole and this changes how the lecturer relates to them (Johnson 2014).
- Planned serendipity, creating in advance a framework to support it (Lombardi and Mark 2004; Lameras et al 2017; Eagle 2004)

8.4 Reflection on phenomenographical results and comparing them to Bruce's phenomenographical study.

As a general overview, the RCT results show that the experimental group on average learned more maths (10%) than the control group. However, a deeper dive is needed to see what is happening with individual students. This is where the phenomenographical approach helps. Many studies / papers have been studied within the literature review as part of this thesis but for this section the one which seemed the closest will be looked at. The Phenomenographical aspects of this study highlighted four categories of description creative, experimental, collaborative and coding.

In particular Bruce has done a lot of research into how student learn. The paper "Ways of Experiencing the Act of Learning to Program: A Phenomenographical Study of Introductory Programming Students at University" (Bruce et al 2004) highlights how students in a university learn a programming language. The game design process in this research did involve using a programming language and there are some parallels between Bruce's research and this study. Bruce identified four categories "following", "Coding", "understanding and integrating" and "problem solving" in her research.

Before we continue comparing these studies some key differences need to be mentioned. Bruce et al (2004) study was a 'pure' Phenomenographical approach and mine was a mixed method approach where RCT was used to test maths skills. In this study, the 'phenomenon' in question was how students experienced maths and for Bruce it was how students experience programming. In this study, students used programming in the Games Design process and for some student programming was a key part. This is why Bruce et al (2004) study was used because it had enough parallels to reasonably compare them both. One final difference and it is a minor difference was the students in Bruce et al (2004) study were first year degree students and in this study the students were first year college students (potentially 2 years younger and just out of school), so less capable.

8.4.1 Creative Approach

The creative approach is the least developed category of description. In this the student start with a creative idea and concept of what the game is to be. These students however struggle the most to make the game with the maths element. In terms of Bruce et al (2004) research, the "creative" is similar to her "following" category. Also, her "following" (Bruce et al 2004:148) is also the least developed of the categories of description. Bruce et al (2004) observed that students in the "following" category "seek feedback from the teaching staff or other elements of the teaching system (such as online marking systems) in order to see if they 'are on the right track'" (Bruce et al 2004:149). In the Bruce et al (2004) "following" category the students need a lot of direction and guidance and in this study's "creative" category, the students have a big picture but struggle in finding a way forward and need more help and guidance from the lecturer to help them than students from the other categories. Bruce et al (2004) argues that students got 'frustrated' sometime (Bruce et al 2004:148). This frustration was observed in this research as the 'creative approach' students having an inability to experiment and take risks in the Games Design process. They sought teacher support often to see if they were taking the right steps.

The role of technology in this research for this category is very much in line with creativity. The students use creative technologies like Photoshop, Pixel Art and the creative Sprite editing functionality of GameMaker. The visual scripting aspect of GameMaker is used but the used coding (GameMaker uses a form of 'c' scripting language which is called gml) aspect of GameMaker is very much avoided. The role maths played was that a big picture was given but the actual maths aspect within the game is poorly implemented. The student struggles to create the maths elements as they want them and although it may look good (nice card designs for example), the actual mechanics tend to be poor (the card game mechanics). The role of the lecturer is much more instructive in this category. The student was aware they couldn't do the coding and went to the lecturer for help and guidance more. It could be argued that it was still a **student led** process because the student went to the lecturer for help. The lecturer then guided the student through the game design process by giving instruction and advice on a regular basis. The game idea is more fixed within the student's minds and students find it hard to change this. From the RCT, a creative approach student (student 1), for instance, demonstrated a -5% measurable maths decrease.

8.4.2 Experimental Approach

In terms of Bruce et al (2004) research, the "experimental approach" category is similar to her "coding" category. Bruce discusses that "coding" approach students use a "trial and error" approach with regards to how they learn coding (Bruce et al 2004:149). From this research, these students are prepared to experiment and test game elements learning as they go along but can get frustrated if this process doesn't work well or they can't find what they need online. "So I could correct any mistakes I had and make it work as best it could" (student 26) this students focus was on getting best grade they could from this assignment (making a game with a maths element within it). The frustration was making the game in the time period they had and getting the best grade they could. Bruce et al (2004:149) echoes this frustration that was also observed in the 'coding' aspect of her research where time is a major factor because of the amount of syntax that needs to be learned or practiced in order to get through the course.

In the experimental category the way the students use technology (role of technology) is better than students in the creative category. For example, from observations (and questioning) it was found that student will use creative technologies like Photoshop / pixel art but then experiment with GameMaker as well, trying to figure out what they can and cannot do with it. They access online resources as well if needed. The role maths plays (they are making a card game) is more defined. The students will understand the mathematic principles better and attempt to code them as. The maths game created usually is ok and works albeit with bugs. In this category, it is a student **led** process and about how the student approaches the game creation process is observed. They start with a creative picture as above but that is not their focus. One focus is that this is an assignment they wish to complete and get the best grade for. These students want to get on with the nuts and bolts of the development. These students learn by doing an experimental learning approach. Kolb describes how knowledge is gained first-hand, instead of hearing or reading about others' experiences (Kolb 1984). The game they have can be different from the initial ideas but is generally what they first visualized. These students have a go then when they get stuck, they ask for help. If help is not given or they struggle following it then frustration creeps in and student struggle. The role of the lecturer is to support if needed and to help the students understand the problem they are having.

8.4.3 Collaborative approach

Interestingly this does not map with any of Bruce et al (2004) categories. No mention is given towards students working together in this paper. That does not mean they did not it was just not mentioned in this paper. This category is a natural progression from experimental approach category. The student's trial and error but this time they collaborate together on various aspect in order to help each other "figure out" how to get an element working.

"I was looking at some tutorials online and someone did do a card game and the majority was a lot like that, so I took quite a lot of that and adapted it and then me and (student 2) and (student 26) worked together to help each other to figure out the bits that weren't explained. The majority of it was we had to change. I had to change all the positions and change it from two people to four people." (Student 3)

The role technology played is very similar to the experiment category, however the students will share their knowledge with peers when asked. The same is true of how maths is implemented, the students share how they are going to implement and even help each other but also make sure the actual games they make are not too similar. This is about working with others on aspects of the game **when** they are struggling. It is hierarchically higher than experimental but has the significant difference that they work with others from time to time. It's about teamwork and also about breaking the task up with other and putting focus on specific areas then sharing with a small group how they solved a particular Games Design issue they found. They tend not to seek help from the lecturer they support each other and rarely ask for help directly. These students choose to work together with others after asking lecturer. They work best with their friends to solve a problem. However, they make the games individually and work on their own for the majority of the time during the game's development process. Compared to the experimental category these students are less frustrated because of the collaboration and find that the problem they have similar to a problem another student is having and working together on problem helps them.

This is very much a student led process. The students develop their game from initial creative concepts but adapt it as they develop it. These students turn to their peers first for support, often finding common problems, then they work together to solve them. The role of the lecturer is to encourage this 'collaborative problem solving" when observed. Helping the students only when needed if as a group they can't figure it out.

8.4.4 Coding Approach

This is the highest category of description for my categories. Bruce et al (2004:152) label this category as "problem solving". Both these categories are very much about overcoming problems (mainly with code) and the journey the student takes to do this. In both categories the students are the ones that engage with the process more than the other categories and develop better code / games.

"When going about learning to program this way the student begins with a problem and sets out to discover the means to solve that problem" (Bruce et al 2004:152)

With regards to the role of technology the majority of the time this category is focused on the coding aspect of the game engine, on how to write the scripts, and more importantly how to troubleshoot problems they have with their code, using online forums and manuals. Here, the maths aspect is the best implemented of all the categories. The game will work as a card game, usually with a computer character that is usually well coded. The coding approach category is the most developed category. In this the student start with a creative ideas and concept of what the game is to be. Then they take this idea and research how to make the game. They may approach the lecturer but in a more limited way, more for checking that they are on right path. These students may struggle with elements, but they are motivated and determined and preserver through any obstacles they find to get the game they want. They are flexible with their initial game idea as well and as the game develops, they may change the game from the original idea.

The role of the lecturer is more about acting as a guide. The student was aware they couldn't do the coding and went to online resources, prepared to research issues they had. It was clearly a student led process because the student took charge of their own learning. The lecturer acted as a guide when approached by the learner.

8.4.5 Summary of categories and reflection

Comparing this study to another is useful from the aspect of how this research ties with another.

Categories of description:

This studies "creative" category is very similar to Bruce et al (2004:149) "following" category with students needing lots of support and struggling to implement the game / code.

The "experimental approach" category is similar to Bruce et al (2004:149) "coding" category with students experimenting with coding (with Bruce's) and game design (this research). However, both sets of students can get frustrated if they feel like they can't move forward.

The "collaborative" category does not link with Bruce's categories, but in simple terms the collaborative students are experimental students that help each other and tend to get less frustrated, however they can produce similar looking games.

Bruce et al (2004) "problem solving" – and the "coding" categories are similar as both are about the troubleshooting, about creating code that works and using forums and other online systems to help them with code and help them debug their code.

Using two students from the study as an example, the affect the categories have on how the students learn and experience the maths can be clarified. Student 25 with a coding category of student and student 30 fitted squarely in the creative category.

These two students had a different approach to making a game withs a maths element in it and the data suggests that both learned maths. However, student 25 had a breakthrough both in coding and making a card game and as a result had a 20% maths increase compared to a 4% maths increase for student 30 who struggled to make the card game. This data is in no way conclusive proof, but it is suggestive that maths was learned more by student 25 than student 30. It also shows that student 25 was able to engage more fully with the games design process. They were free to research and learn through experimentation.

In the FE and maths chapter it was discussed how students need to transition from a school life to a college lifestyle, how well they adjust to their new independence and how this has an impact. It discusses students adapting to a concept of "independence" (DeWitz, Woolsey, and Walsh, 2009) and how some students can transition, and some students struggle to do this. To some extent this concept connects to this research for example in the creative category students struggle to implement a creative picture. They need more support and guidance from a lecturer. They are in essence "less independent" learners. Within the 'coding' category the learners are better able to transition to 'think for themselves' and be more 'independent'. This all is inferred and is beyond the scope of this PhD to pursue, however it is of value and of interest.

8.5 Relationship between this study and Ke's study

As introduced in the chapter serious games and maths. Ke's paper "An implementation of design-based learning through creating educational computer games: A case study on maths learning during design and computing" (Ke 2014) is seen as relevant study (as discussed in section 3:4)

8.5.1 Background to KE study

Both Ke's and this research utilised the power of DBL to stimulate learning. Ke states that DBL is a "powerful learning environment" (Ke 2014). In Kes paper the students design a maths game based on a scenario. In my research they are designing a maths game based on a personalised maths weakness (probability). As with this research Ke argues that students are motivated when making a game (Ke 2014:27). In Ke's paper the students were all at school (no age mentioned but assumed <17 years old). For this study students are aged (18+ years old). Ke (2014) used Scratch to make the games, this research used GameMaker. Scratch has no coding element and uses simple visual coding aspects. GameMaker can use visual coding aspects and pure coding (GM script it is similar to C# coding).

8.5.2 Gathering the results.

In Ke (2014) study student completed a maths competency survey before and after the Games Design process. Also, some students were randomly selected for interviews after each session (Ke 2014:30).

With this study, students were interviewed after the Games Design process and a maths test (see methodology chapter) was given before and after to test students' maths competency. No maths test of the students' abilities was given within Ke (2014) research. However, a t-test was done on the students' responses in the surveys.

The interviews in the experiment in this research were then analysed using phenomenography to find the experiences student had of engaging with maths within the Games Design process.

8.5.3 Comparing the results.

Comparing Ke (2014) results to my study is difficult as mine used phenomenography to look at students' experiences, KE used a survey with maths analysis on the answers. However, some comparisons can be made.

Ke (2014) found "91% of participants reported that they have enjoyed making computer games."

Ke (2014) found "Only 52% of participants, however, mentioned math learning".

Comparing students' comments in Ke's to this research, some interesting parallels are found.

Ke (2014) students view on maths

"Math is everywhere, like math is in everything you do."

"I learned that even though math is everywhere you still have to learn it and when you learn it you will see it more in life that it will be in everything you do. Like cooking, technology, practically everything."

"I need to like math, because you need math in your life. Like we made a cake for my brother's birthday yesterday, we need measurement and (to) mix stuff, like that we need math."

My students view on maths

"Not too bad I think I didn't realise I was doing maths as you do it but looking back on it I realised there is quite a lot of maths in there" (student 2)

Student from pilot study "A little, i now understand that maths is more transferable and needed much more in daily life than i previously thought, especially in game design."

"Yes to be honest it's been a bit more positive"

It can be seen that both set of students have a more positive view of maths after the Games Design process than before. It shows evidence of a 'mind change' taking place within the students with regards how they feel and what they believe about maths. Which was part of the initial hypothesis of this study.

8.5.4 Reflection on KE's and this study

On reflection KE study of 2014 is similar to a pilot study of 2014 (Gallear, Lameras and Stewart 2014). One reflection on this pilot study (see methodology and results chapters) is that one of the lessons learned was student doing maths outside of the class can affect both the maths been tested (if a student is doing maths in other sessions that learn maths there as well). Also, students have experiences with maths outside the context of the study, which can impact how they respond to maths within the study. With this full study the students doing separate maths classes were removed from the experiment. In Ke's it is assumed students did maths as separate classes to this study. However, Ke makes no mention of this in this study, but from this research these maths classes do have an impact and for the pilot study in particular it was believed that it affected the RCT process and the results. For the main study of this research students doing additional maths were removed from the RCT process.

8.6 This study compared to Lameras and Arnab, de Freitas study

8.6.1 Introduction and background

As discussed in chapter 3 Lameras and Arnab, de Freitas (2021) uses phenomenography to investigate the teacher's perspective of inquiry-based learning through serious games within the US schools' system. They argue that They argue that understanding how IBL can help Games Designers can "enable deep and meaningful learning." (Lameras, P., Arnab, S., de Freitas, S. 2021).

8.6.2 Gathering the results.

Lameras and Arnab, de Freitas (2021) gathered data from email correspondence and group discussions with schoolteachers. This study used one to one interview with students which were audio recorded then transcribed into scripts. The data from both these data sources (emails and discussion scripts) was then analysed into categories of description.

8.6.3 Comparing the results.

IBL was the core of these categories but digging deeper into the student experiences, parallels can be drawn from their study and this study. Understanding how the teachers engage with IBL also is of help as this can map with how a lecturer can engage with DBL within this study. Lameras and Arnab, de Freitas discovered four categories of how the teachers experienced IBL and from these categories and roles, some parallels can be formed.

Lameras, Arnab, de Freitas (2021) category A and this study's "creative" category the students are very much directed by the teachers. The teachers are giving them direction, for this study it was giving more of them one to one support for Lameras it is hints and tips. The students for both are more passive in how they learn. The students for both studies need to be encouraged more to get more engaged with the process of making the serious game or playing the serious game.

Lameras and Arnab, de Freitas (2021) category C and this study's "experimental" and to some extent "collaborative" categories are similar in that students are more active learners, willing to experiment and reflecting on what worked and what did not. Both sets of learners engaged with the Games Design process (for this study and the maths element within) or the serious games with its embedded science.

8.7 Reflections and summary

As discussed in the Further Education Culture and Maths chapter, maths and science subjects are part of the STEM educational agenda (House of Commons 2018). Because of this, many educational establishments have been looking for ways to improve STEM based learning. Lameras' et al study (2017) of 165 serious games papers argues that playing serious games enhance intrinsic motivation. The core of both these studies is the utilisation of the intrinsic motivational effects of playing serious games and serious games design to enable the learning of maths or science subjects. It can be argued that an effective way of enhancing STEM based learning can be to use the intrinsic motivational effects of playing serious games and serious games design. Some students in both studies fully engaged with the STEM subject and for this study it can be argued that these students learned more maths as a result. However, phenomenography can only reveal the experiences of what the students (or teachers in Lameras et al (2017)) went through. The phenomenography does not help develop a pedagogical model for future teaching.

For this study, no rigid teaching framework was used. Lameras et al echo this and find that "The role of the teacher in guiding learning via games seemed to be fuzzy and unclear." (Lameras et al 2017). Is this a weakness in the pedagogical approaches used or is it a modern flexible teaching style? From research this educator turned researcher has found that less traditional pedagogical approaches give the best solution to teaching games design (Lameras et al 2017; Ke 2014; Ke and Shute 2014; Ellis 2018).

This study maps the qualitatively different ways a learner learns maths within the context of making a game. The insights gathered from these studies can help educators not just within the context of FE, but all contexts to develop teaching approaches to better facilitate learning maths by using the mechanism of Games Design-based learning within a serendipitous learning environment. To be specific and in reflection to the other studies in the literature; this study can build on previous studies and add the unique flavour of a UK FE college perspective (this researcher found little in the way of UK FE research). Another factor that is unique is the serendipitous learning environment discussed above and in the serendipitous research chapter. This is an environmental aspect that builds on several factors: stealth approach, planned serendipitous / incidental learning within the FE culture. This is, in essence, the serendipitous learning environment.

9. CONCLUSION

9.1 Introduction

The Discussion chapter summarises and reflects on the findings, comparing them with similar studies done (Ke 2014; Lameras and Arnab, de Freitas, 2021; Bruce et al 2004). This Conclusion chapter presents the conclusions drawn from the results of this study, and the limitations of this research. It mentions research that can be informed and influenced from this study. The contributions this research brings add to the fields of Games Design based learning, Serendipitous Learning, Serious Games Design and enhance FE teaching and learning approaches by using technology.

9.2 Summary of research

The results from the RCT showed that on average, students who made the maths game gained 10% more maths skill than those students who just made the control computer game. This is backed up with a t-test to check the validity of this data ($t<0.05$).

The phenomenography, which was looking at the students' experiences when making games, found that the student's engagement with maths fell within 4 categories. The creative category showed that some students had a more creative experience and struggled to move past initial creative ideas. In the experimental category the students had a more a 'trial and error' process and managed to make their games, however they got frustrated when things did not work out as they wished. Some worked collaboratively (in the collaborative category) with others, they helped each other figure out some of the more technical elements, however their games were similar. The final category (coding) were the trouble-shooters who persevered through issues. They struggled but then got breakthroughs and created games and learned maths as well. Some students (n=3) crossed categories. One showed some creative category aspects and some experimental category aspects (student 26), they got a 12% maths skill gain. Another student (7) also showed aspects from different categories, they had creative aspect and collaborative aspects, there maths skills improved by 5%. The final student had both experimental and collaborative category aspects, this student got a 14% maths increase. The three students show that some students were able to transition from category to category and overcome problems that they found and progress.

9.3 Hypothesis and reflection.

The initial hypothesis was that "students learn maths when making a computer game with a maths element". Then from this initial hypothesis two research questions were posed, these questions were: -

> RQ1: Can students learn maths whilst making a computer game with a maths element within it?
>
> RQ2: How students experience learning maths through making a computer game?

To answer RQ1 a RCT was developed to test this and to answer RQ2 a phenomenographical approach was used to analyse the students' experiences.

9.4 Contributions to design-based learning and further education-based teaching

As discussed in the Further Education (FE) and Maths chapter (see chapter 2), FE is one of the most poorly funded educational groups in the UK. In this culture one has to "do more with less". So, utilising an existing system such as Games Design technology and adapting the teaching culture, can reap benefits within this educational culture. Immersive technologies' intrinsic motivational effects, say Lameras et al (2017) can be used to teach tradition STEM subjects in a relatively new and dynamic way. This research has shown that effective use of technology can enhance maths experiences and learning for students. Design Based Learning (DBL) was also used by other researchers such as Lameras and Arnab, de Freitas 2021; Doppelt et al 2008. This is enhanced when utilising a stealth approach like the one Shute et al discuss (2010). An environment is created where the student is free to experiment and develop in what Arnab and Clark, Morini describe as a "playful approach" (2019). The students can get inspiration and moments of revelation or as Arnab and Clark, Morini describe "confusion to light bulb moments" (2019).

The areas to which this research has contributed and given key insights are: -

- Games Design-based learning utilising serendipitous learning and stealth approach. This is seen as a contribution to the research field. This research uses game design-based learning (DBL) and adds a perceived difficult academic subject such as 'maths' within it by utilising a stealth approach. The stealth approach also can be seen to reduce any bias students have when engaging with maths.
- The serendipitous learning environment is seen as a key contribution as it is about how a lecturer can learn to create a classroom atmosphere that is open and flexible and allows "free play" aspects, in essence a 'sandbox' concept. (See sections 7.5 Outcome Space and 8.2.4 Reflection on Phenomenography and RCT Results). This environment is set up to enable the serendipitous learning and "serendipitous encounters" (Eagle 2004; Lombardi and Mark 2004). In the non-academic world, Steve Jobs created an environment within Apple that enabled "serendipitous interactions" (Znet 2021). This is also enhanced as the students are using an immersive technology (games engine) and become intrinsically motivated to learn with the lecturer taking the role of facilitator and mentor and leaving the students to explore the games design

process by themselves (see section 7.5). Bruce et al (2004) reflects that a "program of study can be delivered in a way that enables a deeper learning experience." (Bruce et al 2004).

- Further education (FE) (see chapter 2) is the ignored middle brother of the UK education system. Schools get funding and support, and Universities get funding grants and recognition. If this teaching and delivery style is adopted in FE, this thesis shows that there may be benefits to the teaching not just of maths but of other STEM subjects. This is also seen as a key area that this research contributes to especially in FE education in the UK. This has had an impact on the FE college I work in with lecturers adopting this approach themselves.
- For the wider research area this research adds to the field of serendipitous learning, design-based learning, stealth approach, and the use of technology in education.

9.5 Limitations and reflections

There are some limitations associated with the research. First, the research was done on a part time basis in an environment that is not supportive of research, with significant curriculum constraints and time limitations. The study was done to a limited number of students (n=30 for the RCT, n=7 for the phenomenography).

One good point is that this research was done within the curriculum. There was no external researcher involved. The insights and results are hence done fully immersed within a teaching curriculum and teaching environment. The students were observed during a typical classroom session where the students made the games, and these observations are all recorded. As opposed to an external researcher coming into the classroom and interviewing the students.

A college-based maths assessment process called BKSB was used. It was chosen because by default all FE students are given a BKSB maths assessment. (BKSB RCT rationale in detail in section 5.5.1). Another separate maths assessment process was considered but rejected because feedback from the pilot study indicated students felt it was unfair doing multiple maths assessments and this created a bias which worked against the research process being undertaken. Using the BKSB also supported the stealth maths approach this research undertook and from that perspective it can be argued that the BKSB was the best way to effectively assess maths in the environment of poor maths achievement. BKSB does not give a specific percentage-based breakdown of specific maths areas such as probability. It can only give an indication of a maths weakness.

For the phenomenography, additional interviews would have been better, however due to curriculum pressures this was not possible. Also looking at other studies (Ke's 2014 study in particular), interviews were done pre–games design process. This could have added richer data. Students were observed during the games design process and possibly more anecdotal evidence could have been added. This additional evidence could have added more research data, specifically the phenomenographical data.

9.6 Future research

Design based learning is in its infancy and more research is needed to illicit good teaching practices and how to use technology within them, especially in the digital technology fields.

With the impact of COVID19 teaching was moved from a classroom-based teaching to online based teaching using digital technologies. This was a global phenomenon where the teacher/lecturer had less face-to-face contact with students and the students worked in a more independent way than ever before. Whilst this thesis has been written, teaching has gradually been moved back to classroom-based teaching, but some will remain online.

One area that needs further researching is the "serendipitous learning environment" concept that was discussed in the Discussion chapter. Having an environment where students can be free to explore and develop their own learning in a safe, "sandbox" type environment may be an appealing research concept.

In summary the research areas could be:

- Further research on design-based learning and its impact on learning. This is a new and growing pedagogical approach that needs further research.

- A longitudinal phenomenographical study on the use of serendipitous learning and stealth approach in education and how this can be planned in a curriculum. This is a growing pedagogical approach that needs further research.
- Adapting design-based learning into online mode in line with a growing blended learning approach globally.
- Using technology to teach maths. This is a broad area and links with serious games and gamification of maths.
- Adapting this FE research to schools and university environments. A more phenomenographical based approach maybe more appropriate for smaller groups and also better for an individual teacher / researcher to do than a larger scale RCT with a large student body involvement and all encumbering ethical implications.
- Build on Phenomenographical approach to link with FE culture research with regards to how students adapt to being in a FE college (from a school) and adapting to 'independence'. Which links with the different categories of description found in this research. (See FE chapter).

This is a broad list of research ideas that are in no way exclusive.

9.7 Personal reflection

This has been a long part-time research journey that started with this researcher having a "serendipitous" encounter with a university lecturer at a games convention who was promoting PhD studies at a university.

For 18 years I have observed students who struggled with any sort of maths during my times as a lecturer and have tried many different approaches before even embarking on the PhD journey. The lightbulb moment came to me as I began to teach games design and watched the students engage in a deep manner with this subject as they made and played computer games. I asked myself could a student learn maths and possible learn to enjoy maths through the medium of making a computer game.

It has been a long and lonely road at times. I have moved from lecturer to an amateur researcher and learned how to embed research in a curriculum. I have many memories of watching students developing games and having "breakthrough" moments. It has been very satisfying to be part of their journey and has inspired me to find better ways of helping students to overcome their own internal barriers not just to learn but enjoy the learning journey they have been on. That may sound clichéd but it's true in my case. Interesting as an additional point; student 2 has recently started work as a 'maths' tutor teaching and helping students learn maths in the college I work at.

I have learned many new skills, both as a lecturer and in particular as a researcher and have 'mainly' enjoyed this research journey. I have learned interviewing skills and reflecting on feedback given and learned how to keep the interview process open and get a student to reflect on themselves effectively. The phenomenographical research is seen as an aspect that will be used more in the future.

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11. APPENDICES

Appendix 1: Participant Information sheet

Participant Information sheet

Dear Student,

Wayne Gallear is conducting a research study to look at how students' study and engage with the course a student is undertaking. The focus been on Games Design. The purpose is to look at how these courses can be improved in future.

Students who wish to be involved will be given an informal one to one interview where a series of open questions about their studies will be asked and this will be recorded. The data is kept anonymous (students name is kept private).

The anonymous data from this interview is what is needed in the research and may be using in public research papers. This data is securely kept and destroyed after the study is completed.

This research is not part of South Leicestershire College but is part of PhD research program. However, the results will impact on courses of study at South Leicestershire College.

There is no obligation to be involved in this study but if you want to want to be involved and are happy to be interviewed, please complete the consent form attached. If you are 18 or under, please speak to your legal guardian (parents) to complete the form attached.

Students have the right at any time to withdraw from the study and have any of their data if collected removed from the study.

Making a Complaint

If you are unhappy with any aspect of this research, please first contact Wayne Gallear at South Leicestershire College.

If you still have concerns and wish to make a formal complaint, please write to

Dr. Craig Stewart

Deputy Head Computing Coventry University
Coventry University
Coventry CV1 5FB

In your letter please provide information about the research project, specify the name of the researcher and detail the nature of your complaint.

Appendix 2: Participant Consent Form

Participant Consent Form

Dear Student,

You have been invited to take part in a research study looking at how students' study and engage with the course of study a student is undertaking. The focus been on Games Design. The purpose is to look at how these courses can be improved in future.

Before you decide to take part, you must read the accompanying Participant Information Sheet.

Please do not hesitate to ask questions if anything is unclear or if you would like more information about any aspect of this research. It is important that you feel able to take the necessary time to decide whether or not you wish to take part.

If you are happy to participate, please confirm your consent by circling YES against each of the below statements and then signing and dating the form as participant.

1	**I confirm that I have read and understood the Participant Information Sheet for the above study and have had the opportunity to ask questions**	**YES**	**NO**
2	**I understand my participation is voluntary and that I am free to withdraw my data, without giving a reason, by contacting Wayne Gallear at South Leicestershire college.**	**YES**	**NO**
3	**I understand that all the information I provide will be held securely and treated confidentially**	**YES**	**NO**
4	**I am happy for the information I provide to be used (anonymously) in academic papers and other formal research outputs**	**YES**	**NO**
5	**I am happy for the interview to be audio recorded**	**YES**	**NO**
6	**I agree to take part in the above study**	**YES**	**NO**

Thank you in advance and can you please complete and return if you want to be involved in this study.

Signature / Legal Guardian (if under 19): Date:

Research Signature: Date:

Appendix 3: Original Pilot study experiment design process (pre 2014 pilot concept)

Experimental Design Process

The participants and resources

The 26 students are 18- and 19-year-old males all doing the second year of a BTEC National in IT qualification.

They are further split into two groups of 13 students, Group A and Group B. The split is based purely on fact that the maximum IT classroom size is approximately 16 students. It is not based on academic ability and both groups have students of mixed academic abilities.

Group A is taught on Wednesday mornings and Group B is taught on Thursday Mornings both are taught from 9AM till 12:15PM with a 15-minute break. All the students use laptops with 'Gamemaker' software installed and have wireless access to the college network and internet.

Summary of Experiment

Embedding STEM based research into games development.

The students are given 2 assignments as part of a BTEC National Qualification course they are currently studying. The unit they are doing is computer Games Design and both assignments are the creation of computer games.

One assignment is set as a control and is a platform game. The students are shown some example games and a simple template to work from. The students then develop this game, documenting as they go then test the final product along with reflecting on the process and how they overcame the problems they encountered. (Problem based learning and reflective based learning pedagogies)

The Second assignment is the experiment and is a maze game, however with a maths based twist. This is where the STEM element comes in. The maze consists of several levels of increasing difficulty in which several maths based problems / puzzles have to be resolved in order to progress to higher levels of the game. Score is awarded for solving these maths problems / puzzles.

The student will have to research maths based problems and puzzles at an appropriate level of understanding. The level should be GCSE Grade C Maths level. The students are encouraged to access maths resources that are available within the college. This is particularly relevant to students who are doing additional Maths based units such as GCSE Maths' qualification's or Functional skills Maths units.

The students are given assignment briefs for both control and experiment with an overview of the problem to be solved and also the standard BTEC learning goals to be achieved by completing both assignments. These assignments will form part of the Games Design unit the students have to complete in order to complete the course. It should be noted that for this unit the students would be required to complete two assignments to fulfill BTEC requirements to pass the Games Design unit. The change made to make the assignment into an experiment is well within BTEC specifications and also a major point is that this experiment is hidden from the student who believes they are doing ordinary computer games assignments.

Gant chart of game making process for control and experiment

Mathematics level assessed (Mathematics one test)

Control	**Feb**	**Mar**	**Apr**	**May**
Game Created	GpA	GpA	GpB	GpB
Documentation of game	GpA	GpA	GpB	GpB
Reflection on game	GpA	GpA	GpB	GpB
Mathematics level assessed (Mathematics two test)				
Experiment				
Game created	GpB	GpB	GpA	GpA
Documentation of game	GpB	GpB	GpA	GpA
Reflection on game	GpB	GpB	GpA	GpA
Mathematics level assessed (Mathematics two test)				

As can see neither group is penalized as both do the control and experiment.

Group A does the control and then experiments and Group B does the experiment and then control.

Goals of Experiment

The goal of this experiment to evaluate whether the mathematic ability of students is increased (or not) when doing the experiment!

Professor Wolf in review of FE education paper found that less than 50% (Wolf, 2011) of students obtain a GCSE grade C (or above)

> English and Mathematics GCSE (at grades A*-C) are fundamental to young people's employment and education prospects. Yet less than 50% of students have both at the end of Key Stage 4 (age 15/16); and at age 18 the figure is still below 50%. Only 4% of the cohorts achieve this key credential during their 16-18 education. (Wolf, 2011)

The student's mathematical ability will be measured using the college standard tests all students do when enrolling on a course.

Data Collection

There are three Maths tests done and this assessment is done for both groups. The student's mathematical ability is measured regardless to whether they are doing a control or experiment based assignment.

Interviews / interview procedure

In addition to Math tests the students will be interview on a one to one basis after both experiments to get their feedback on the process and the assignments. Did they figure out that it was an experiment they were involved in.

Ethics

The students are enrolled on a BTEC National in IT course. They are doing a variety of units and each unit has several assignments they have to complete in order to gain a BTEC qualification.

The 'experiment' is purely embedding STEM based studies within a standard BTEC unit.

Traditionally STEM based units are difficult to get the students to get engaged with and results are usually poor. Computer Games Design is a unit which students enjoy doing and engage with and get good results when doing. (SLC student data 2012)

"Students, who believe that their previous failures were because of their disabilities in school assignments learning, probably don't expect to be successful in same assignments, so unlikely they will try more."(Pouyamanesh and Firoozeh, 2012)

This experiment is to embed STEM subjects within a Games Design unit, hopefully getting the students to engage with STEM subjects in an exciting way.

From an ethics point of view data collected will be kept anonymous and any documentation with not name students directly. The assignments that the students work on will form part of the BTEC course work and is used for grading purposes and not be used as part of this experiment. I have worked with these students for three years now and have been their personal tutor. All students are 18+ age and the assignments are compulsory, but they will consent forms will be used if a student wishes to be involved in the experiment.

Data Analysis

The data is collected using both **Quantitative** and **Qualitative** approaches.

Quantitative from the maths assessments and then compared to each other for both groups

Qualitative is using a phenomenographic approach is used in the interview process. The point is to get to understand how the students felt about working out maths problems in a game.

Questions like:

How did you feel about solving maths problems in a game?
Did it detract from the gaming experience?
Did you realize this was an experiment?

Will be asked in one to one interviews with the students.

Appendix 4: Experimental Plan for RCT study

Experimental Plan: Summary description of the system: Participants complete a maths assessment (using the popular commercial online BKSB test system) before and after making for one of two computer games from an assignment given as part of a college course (see appendix 6). The choice of what game they make (as described within the assignment) is done by random allocation. The participants in the study will make both games but the order they make them will be random. The second game creation is not part of the experiment.

Targeted user: Targeted participants of the study are students enrolled on a level 3 BTEC Games Design course at a local FE college. All participants are required to be 18 years and older.

Goal of the experiment: The goal of the experiment is to test the hypothesis "Students learn maths whilst making a computer game!". One of the games has a maths element as part of it (experiment game). The other game has no maths element (control game).

T-test null hypothesis: Statistically comparing the mean math test results pre and post of the group of participants who created ***experiment game*** versus the pre and post maths results of the participants who created the **control game**. Testing this hypothesis using a t-test to get a p value. If the paired t-test p-value < 0.05. This equates to 95% probability the hypothesis holds true.

Variables / assumptions: Participants are not doing any external maths class whist involved in this study. Maths test data is parametric in nature and follows a normal distribution curve. Making any computer game involves the use of coding. Participants would be learning coding and hence some maths this way as part of Games Design process.

Measures: Educationally all participants are roughly educationally equivalent who came from a school background and are now full FE students. All have GCSE grade C in maths or above pre study (this reduces / eliminates external maths sessions).

Experimental design process:

Experimental Procedure Start: Participants are all part of a Games Design courses they choose to enrol on as part of a course of study at an FE college in the UK. During the induction and start of this course the participants were introduced to the study and invitations were given to the study in the form an informal discussion and then participant information and consents form were given out at this stage. Out of 68 students who enrolled on the course 30 choose to participate in this study and completed the study consent forms. All the students (n=68) then completed a BKSB Maths and English assessment as required by the college enrolment process. The results from this test were fed to the researcher. Of the (n=30) participants it was observed from the BKSB data that n=11 had a specifically identified maths weakness with probability (BKSB reports highlight maths weakness participants have but not questions they got wrong). From this data it was decided to utilise this maths weakness as the specific math element with the game they make (the experiment game). Also, from observation of the students doing the BKSB (see BKSB sample in Appendix and methodology chapter) students were asks question using cards. So, the concept of a card game became the experiment (The game they made with the maths element within it), specifically a pontoon game / blackjack game to make. The control (non-maths game) was a space invaders game to make.

Mathematics stealth approach utilised: All the students enrolled on the course (n=68) were involved in making the 2 games and doing the BKSB maths assessments. The participants not involved in the study no data was used. This was part of the stealth approach process utilised to **1)** hide the maths elements with the Games Design process **2)** The students involved in the study would not be treated differently or do any additional elements compared to their peers therefore hiding the maths aspect research **3)** The Games Design course required them to make 2 games to be assessed and created a vehicle for this study. **4)** all students are required to complete BKSB assessments when they enrol on any college course, this process was utilised for the maths test assessment rather than students completing a separated maths assessment just for this study. That in the pilot study was identified as 1) enhancing perceived and observed resentment / apathy toward maths subject. 2) even seen as “unfair” by students doing additional maths test compared to their peers.

Researchers' role: The researcher managed the Games Design lecturers who taught the Games Design course and removed themselves from influencing the participants Games Design process. The research informally observed the students making the games during teaching sessions but did not influence them or support them in the Games Design process.

Experimental Procedure: After the initial introduction and induction and BKSB process the course started. The students were allocated to teaching groups and randomly allocated to make one of the two games first. After completing this game then then completed a second BKSB maths test.

Ethical data approach: Participants involved in the study could withdraw whenever they wished and consent forms and BKSB data was securely kept on college system.

Appendix 5: Experimental Plan for Phenomenographic study

Experimental Plan: Participants make a serious game with a maths element within it.

Targeted user: Targeted participants of the study are students enrolled on a level 3 BTEC Games Design course at a local FE college. All participants are required to be 18 years and older.

Goal of the experiment: The goal is to use phenomenography to discover qualitatively different ways a student experiences of maths through the mechanism of making a computer with a maths element within it.

Variables / assumptions: Participants are not doing any external maths class whist involved in this study. The students is exposed to maths is through Games Design process. Participants would be learning coding and hence some maths this way as part of Games Design process. This would be part of the maths experience as well.

Measures: Educationally all participants are roughly educationally equivalent who came from a school background and are now full FE students. All have GCSE grade C in maths or above pre study (this reduces / eliminates external maths sessions).

Experimental design process:

Experimental Procedure: Participants are all part of a Games Design courses they choose to enrol on as part of a course of study at an FE college in the UK. During the induction and start of this course the participants were introduced to the study and invitations were given to the study in the form an informal discussion and then participant information and consents form were given out at this stage. The Phenomenographic approach was due to be carried as the RCT trail concluded (see appendix 6). As discussed in appendix 6 the game with the maths element as was a card game (as perceived math weakness was probability). Of the 30 students doing the RCT trials 13 of these students were chosen for the phenomenography study eleven were male, two females, all had turned 18 during the academic year and all part of experimental group. The rationale behind these 13 was mainly due to curriculum time constraints and these 13 seemed to be from a RCT point of view a good cross section of the student body and these students were all open to the interview process. As the RCT process completed these 13 students were interviewed on a one-by-one basis in separate room and were asked if an audio transcription of the interview could be done. All the participants agreed to this.

Interview Introduction and rational:

To recap the purpose of this is to elucidate the participants experiences of maths whilst making a game with maths elements within it. From the initial pilot study qualitative approach of using 10 questions. It was felt more 1) questions were needed and a 2) more structured approach to the questions and questioning technique was needed. This resulted in more questions been asked and more structured approach. The participants to recap are all Games Design students who expect to be asked about their Games Design experience (see assignment in appendix 4). They were prompted by the assignment brief to expect this and so the questions were at first geared to this "embedded" approach that Shute used in their research (Shute et al 2010). This allowed the participants to relax and answer questions they expected. The first 4 questions were all geared towards this. The next set of questions where about the context of the game. As in making a card game. Once again, the participants had an expectation that they would talk about the specifics of the game, in this case a card game. However, these questions allowed to researcher to gather students experiences of making the maths-based game. These questions where open in nature allowing for a free-flowing process. Prompts were used.

For example

How did you feel when you realised you were doing a card game?

The next question was did you like it? Then why did you like it or not?

They were encouraged to be open and because the research was not a stranger to them but someone they knew as a course manager, and they had seen them at induction and sometimes during game development. This created a repour and allowed a free-flowing conversation.

The questions progressed as the interview continued eventually focussing on maths at the end. How do the students feel about maths and also to see if they were aware they had been making a maths game?

During this process no mention was given by the interview that they made a maths game.

Questions asked:

general questions

- So, what did you think of the assignments?
- How did you feel about doing the assignments?
- How would you think of the assignments in terms of difficulty?
- Can you give me an example of a subject you've learnt?

Questions about Games Design process

For the card game.

- How did you feel when you realised you were doing a card game?
  Prompt: Would you have preferred to make the space invader game?
  Prompt: Or another game and why?
- What did you like?
- Why did you like about it or not?
  Prompt: can you be more specific?
- What do you think you learned during its development?
  Prompt: What was it?
- What did you do to learn it?
- Why did you it like this? / What were you trying to achieve?

Questions about Games Design with a view of learning maths

For the card game..

- How would you identify any math elements?
- Why you think this is a math element?
- What element do you think this is?
- When you created the game how did you feel about using the maths elements within this game?
- Do you think you learn any maths when you created the game?
- How did you approach this learning? For example, did you practice it by yourself did you discussed it with students or with teacher? Did you do a related activity?

Concluding question

- How do you rate your maths?
- Give us a 1 to 10 scale how good are you?
- What GCSE grade do you have in Maths? (Check real grades)
- How hard did you find the maths during these assignments?
- What game would you create if you wanted to teach maths and why?
- Do you think your opinions towards maths has changed when making these games?

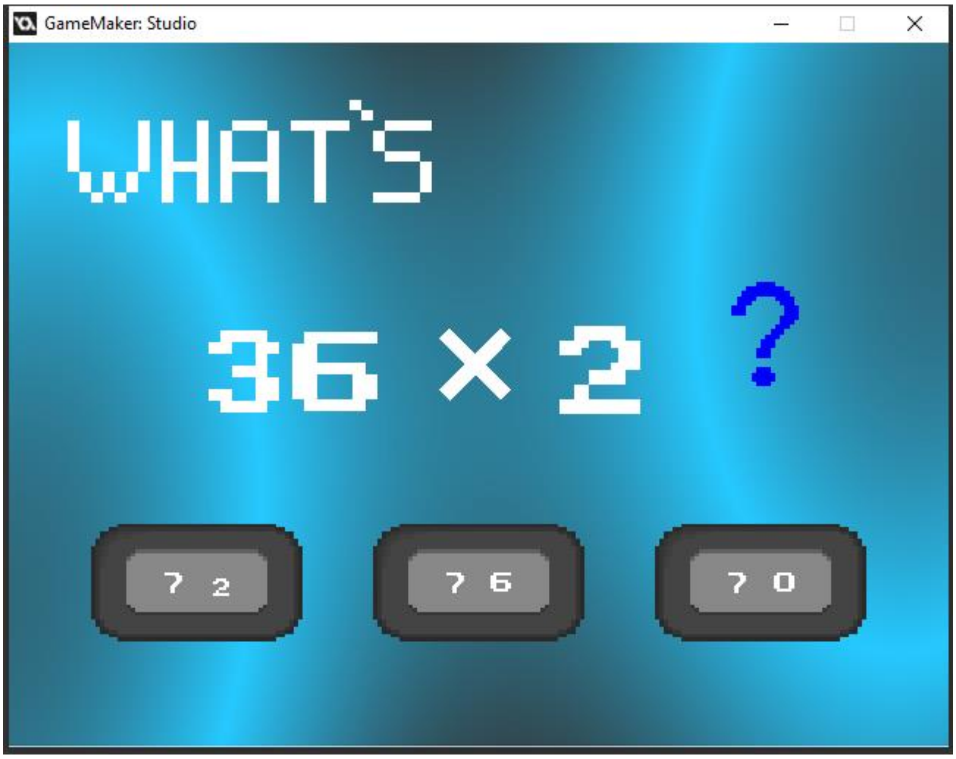
Researchers' role: The researcher managed the Games Design lecturers who taught the Games Design course and removed themselves from influencing the participants Games Design process. The research informally observed the students making the games during teaching sessions but did not influence them or support them in the Games Design process. The researcher interviewed the participants at the end of the Games Design process.

Ethical data approach: Participants involved in the study could withdraw whenever they wished and consent forms and BKSB data was securely kept on college system.

Data analysis process:
After all the interviews had been concluded all the data from the audio recording was transcribed into scripts. These scripts then formed the basis of the phenomenography process and were used to identify the various qualitative ways the students experienced the maths Games Design process.

Appendix 6: Pilot study mathematics game screenshot

For sake of completeness these are screenshots of a game from original 2014 pilot study showing "brain man game" and a simple sample question that the game asked.



Appendix 7: BKSB test paper example showing probability questions.

The following image is from a sample sheet showing examples of questions that students would be asked. Screenshots of the real BKSB is copyright protected and not included in this thesis. However, this gives an indication of some of the questions students were asked and this researcher witnessed questions like this asked to the students.

bksb
Excellence in skills development

PROBABILITY
LEVEL 2
HD2/L2.1
16

Exercise 1 **Independent Events**

Show all answers to the following questions as simple fractions.

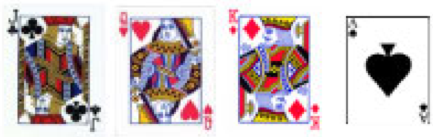
1) If you draw a card from a full deck of 52 playing cards what is the chance that it will be:

a) the ace of spades? ________

b) the queen of hearts? ________

c) a king? (There are 4 kings in a pack of cards.) ________

d) a picture card? (There are 12 picture cards in a full pack.) ________



2) Abigail has 17 chocolates left. As she offers her friend a chocolate she realises there are now only 2 of her favourite truffles left. What is the probability that her friend will choose one of her favourites if she chooses a chocolate at random?

____

3) An adult education class has eight women and six men on the register. What is the probability that the first person on the register is a woman?

____

4) There are 200 employees in the building and 6 will be chosen at random to go on a course. How likely is it that Fern's name will be drawn out?

____

5) Jonah has 3 sisters and 4 brothers. What is the likelihood that the person trying to get into his bedroom now is one of his brothers?

____

bksb
Excellence in skills development

PROBABILITY
LEVEL 2
HD2/L2.1
16

Exercise 2 **Combined Events**

1) What is the probability of Ryan getting 3 heads in Example 1? ________

2) Using the tree diagram shown in Example 2, complete the table to show the possible outcomes of throwing 2 dice together, i.e. 1 + 1 = 2 etc.

	1	**2**	**3**	**4**	**5**	**6**
1	2	3				
2						
3						
4						
5						
6						12

3) From your table, you will see that there are 36 possible outcomes. The probability of getting 3 is $\frac{2}{36}$ (or $\frac{1}{18}$) because there are two outcomes giving the answer 3.

What is the probability of getting:

a) 2 ________

b) 4 ________

c) 8 ________

d) 12 ________

4) What outcome is most likely? ________

5) Using Example 3 as a guide, draw tree diagrams to show all the possible outcomes when two balls are picked from a bag containing:

a) 2 yellow and 4 green balls;

b) 3 blue and 4 pink balls;

c) 4 red and 5 white balls.

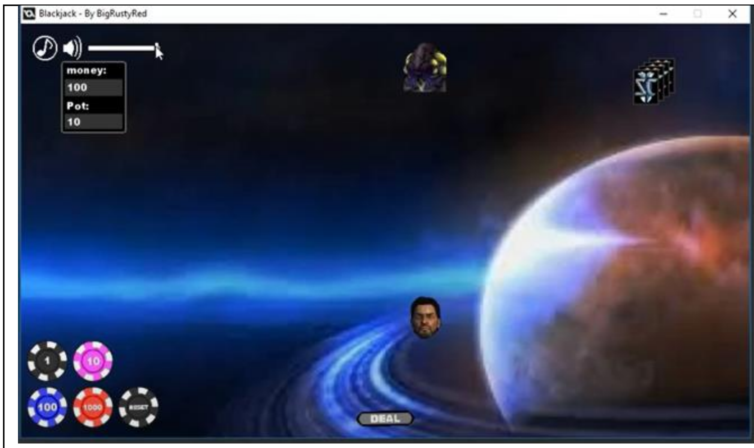
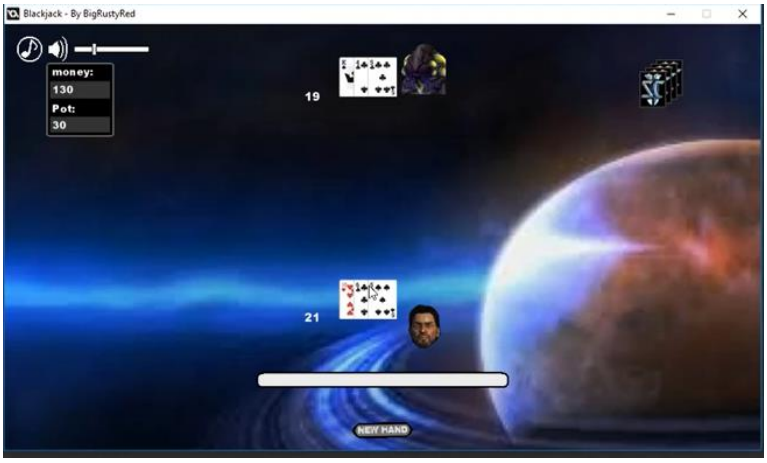
Appendix 8: Pontoon / Blackjack game screenshots

Students were required to make a card game, more specifically a pontoon styled game, where players had to get as close as possible to 21 with the face values of their card. The picture cards were valued at 10 points and the ace could be valued at 1 or 11 points (player choices). The character *they* controlled needed a process to get more cards (the hit or twist action), or to not get a randomly given card if they felt they were close enough to 21 to win. The other computerised players needed to decide the same whether to have more cards or stick with cards they had. Then at the end the players (whether human or otherwise) nearest to 21 (or less) wins the round. Students were encouraged to add elements such as music and sound effects and any other elements they felt were appropriate.

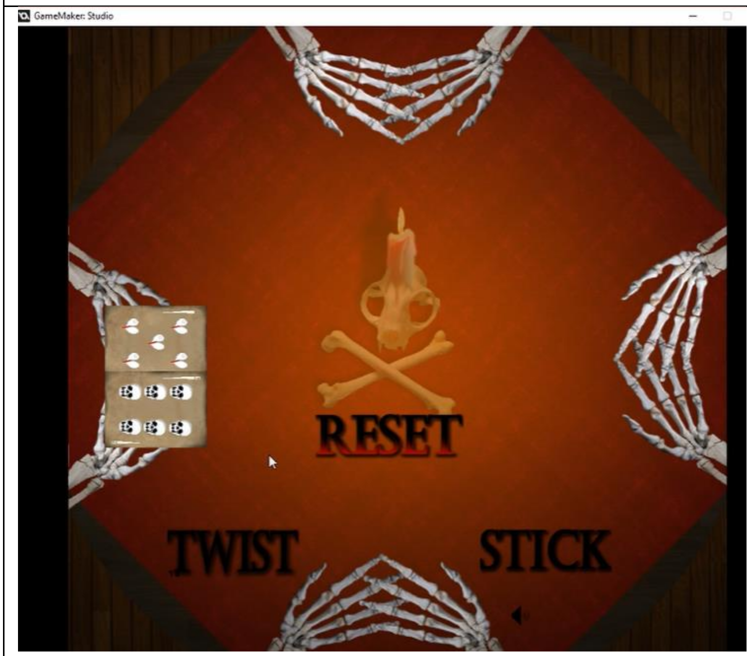
One used a space theme (student 4) another used a fantasy theme (student 1) for their game. With the first example below, student 4 makes the card player against one computer opponent. This game had extra elements like sound and a pretend betting aspect. The player could hit, miss or stand. With the hit the player was randomly given another card and if the total value of the cards was above 21, they went bust. As seen from screenshots a sample hand is played where the player wins the round.

The next is a more creative version of the game using a fantasy theme where the player used a mouse to move over the cards. This game was problematic and only partially worked however it showed the potential of what they wanted to achieve.

These are screenshots of card games created from of the students.

 Student 4: Screenshot 1	Student 4 used a space themed game. Using chips to bet against one computer opponent. It has extra elements like sound.
 Student 4: Screenshot 2	As you can see, a game has been started and the player has a score of 16 and the computer has a score of 10.
 Student 4: Screenshot 3	This is the final hand. The player wins the round with a score of 21 and the computer has a score of 19. Also the player gained additional "money" from winning the round.

 Student 1: Screenshot 1	This fantasy themed game partially worked. Student 1 got the sprite animation and used 'Photoshop' to edit each card. All the artwork is part of this fantasy themed card game concept. This included the background and the computer player faces which were all were animated during the game.
 Student 1: Screenshot 2	Cards got highlighted when you move mouse over them. *"The King, Queen and Jack, they were fun to do the art for them."* (Student 1)

 Student 1: Screenshot 3	Also face changed when player lost the game. *"The coding side of things and the maths are the things I found hard. It was very challenging."* (Student 1)
 Student 1: Screenshot 4	Creative approach - student 1. The game didn't work as well as they would have liked but they were pragmatic about it. *"I more or less got the card game working"* (Student 1)