Investigating the Impact of Mathematics Game-Based Learning among Higher Education Students

Natalee Knoop (BSc, MSc, PGCE, QTS)
November 2024

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Department of Educational Research,

Lancaster University, UK

Declaration of Authorship

I, Natalee Knoop, declare that I am the sole author of this thesis titled ‘Investigating the Impact of Mathematics Game-Based Learning among Higher Education Students.’ I confirm that this work has not been submitted for the award of a higher degree elsewhere and has been done solely to fulfil the partial requirements for the Doctor of Philosophy degree at Lancaster University, UK. I declare that the word length of this thesis is 50,551, which is in accordance with the authorised word count allowance.

Signature ……………………………………………………………….

Investigating the impact of Mathematics Game-based Learning among Higher Education students.

Natalee Knoop

Abstract

Many Caribbean students who enter higher education (HE) do not have a firm mathematics foundation. This impacts their academic outcome. A mathematics game-based learning (GBL) intervention was conducted to investigate its impact on students' learning outcomes and learning experiences and determine the potential of GBL as a pedagogical consideration in this context. This study examines the impact of mathematics GBL on students' academic performance, their perceived satisfaction with the elements of the self-determination theory (SDT): autonomy, competence, and relatedness, their learning experience of flow, and their perceptions of the benefits and challenges of mathematics GBL in their classroom. The intervention was conducted in an HE institution in the Caribbean among three groups of undergraduate chemistry students. This is convergent mixed methods research conducted through a pragmatic lens and employed quantitative data (pretests and posttests, students' final grades, Likert responses) and qualitative data (questionnaire and focus group) to facilitate a rounded overview to answer the research questions. Results suggest that the intervention had a statistically significant impact on students' pretest to posttest scores and did not impact their final course grades negatively; students' basic psychological needs of autonomy, competence, and relatedness were satisfied; and some students may have experienced flow. Overall, the students overwhelmingly enjoyed the learning experience; it was positive for their well-being; they were motivated and engaged in the learning environment, and their mathematics knowledge and understanding were enhanced, resulting from the intervention. The findings add to the theoretical discourse of flow and SDT; for example, it is possible to optimise and enjoy a learning environment even if all flow elements are not in alignment; some Caribbean students are motivated by competition and leaderboard, and autonomy, competence, and relatedness promote flow in the GBL environment. These insights can inform practitioners, policymakers, and other education stakeholders.

Acknowledgements

Firstly, I would like to express my sincerest gratitude to my supervisor, Dr. Julie-Ann Sime. It was an absolute pleasure being supervised by Dr. Sime. Her continued support and meticulous guidance helped to shape my knowledge and understanding of what was required to complete this thesis. Dr. Sime was thorough with her constructive feedback, and I learnt a lot from her. In addition to all of that, I would really like to thank her for her display of exemplary interpersonal skills, which always made me feel at ease during our interactions. For me, that has been a crucial part of this whole process.

I would also like to express my heartfelt gratitude to my family and colleagues for supporting me in several different ways. My husband, Philip Knoop, for being my constant pillar of strength and support through this journey; my mother, Babette Watson, for travelling from another country to come and assist me; my four children, Chris-Ann, Christopher, Liam, and Nala, for each, calling my name, a few times less, Mrs. A. Hyde for all her consideration and logistics assistance, Dr. A. Gayle, for her data collection assistance, our numerous education research discussions and continuous support, Dr. E. Gordon for her continuous support, kindness, and encouragement. Dr. Durham-Philip for her kindness and encouragement; Dr. L. Smith for always checking on my progress; Mr. L. Soler for all the information technology assistance; Dr. Samuels and Dr. C. Reid for discussing psychology with me; and all the other friends and colleagues for their numerous words of encouragement.

Thank you all for contributing to the completion of this thesis.

Contents

List of Figures and Tables

1 Introduction

1.1 Overview

This study aims to investigate the impact of mathematics game-based learning (GBL) on students' overall academic performance, their perception of flow, their perceived satisfaction with the elements of the self-determination theory (SDT): autonomy, competence, and relatedness, as well as their perceptions of the benefits and challenges of mathematics game-based learning in their classroom. The mathematics game-based intervention was conducted in a higher education (HE) institution in the Caribbean among three groups of undergraduate chemistry students. The participants comprise students from two sections of General Chemistry I and one section of General Chemistry II. There was a total of 43 participants among the groups. All three groups had the same teacher.

In addition to being a standalone subject, mathematics is incorporated into several other disciplines at the HE level, but many students have a negative attitude towards mathematics (Leacock, 2015; Li et al., 2021) and hence are not motivated to learn it. I have seen this first-hand as a mathematics lecturer for many years, and innovative ways are needed in the mathematics classroom to motivate students to learn and keep them engaged in the learning environment. After experimenting with GBL in my classroom, I recognised the potential advantages that may be derived from using it in mathematics teaching and learning environments. A learning environment should not only promote competence but also be enjoyable, inclusive, and conducive to overall student well-being; I believe a GBL environment can achieve these positive attributes in HE mathematics classrooms across the region.

Krath et al. (2021, p. 2) define game-based learning as 'the achievement of defined learning outcomes through game content and play and enhancing learning by involving problem-solving spaces and challenges that provide learners, who are also players, with a sense of achievement.' Game-based learning inclusion in higher education teaching and learning can motivate students (Koparan, 2019; Shaker et al., 2021; Rosillo & Montes, 2021; Zabala-Vargas et al., 2021) and enhance their learning outcomes (Abdu et al., 2015; Gil-Doménech & Berbegal-Mirabent, 2019; De Troyer et al., 2019). This positions GBL as a tool that may be used in my context to improve students' learning outcomes in a suitable learning environment.

Research in GBL has gained traction in the last few years; however, there is still a need for theoretically sound research at the HE level, where mathematics is concerned. In fact, most of the mathematics research conducted has only focused on the primary and secondary levels, so more research is needed at the tertiary level to establish GBL's full impact in the mathematics classroom. Additionally, it is not yet known how GBL impacts HE mathematics classrooms in the Caribbean despite its potential advantages and the need for innovative solutions to mitigate unsatisfactory mathematics performance. Further to this, to the best of my knowledge, no existing study takes an interdisciplinary approach and looks at the impact of mathematics GBL in a chemistry classroom in my context.

This convergent mixed methods research addresses these gaps and presents key findings and limitations of GBL in higher education mathematics with recommendations for the directions of future research in the area.

1.2 Research Context

A clear understanding of the research context is vital to explain the outcome's relevance accurately. In this section, I provide an overview of the research setting, including the geographical location, study institution, and the role of competition in the Caribbean education system. I also briefly outline the interdisciplinary nature of the classroom environment, particularly involving mathematics and chemistry. Additionally, I discuss some possible reasons why students face mathematics challenges in the Caribbean's interdisciplinary classroom. Collectively, these components help to situate the study and establish the study rationale. Special attention is given to the dual-enrolment (DE) programme, which gives students an early introduction to university life and undergraduate-level courses.

1.2.1 Study Location

This research was conducted in the Cayman Islands, a British Overseas Territory in the Western Caribbean, with George Town as its capital. The Cayman Islands comprise Grand Cayman, Cayman Brac and Little Cayman. The research was done on Grand Cayman, the largest of the three islands. As of 2023, the population of the Cayman Islands was 84,738 persons, with approximately 39,068 Caymanians (46.1%) and 45670 non-Caymanians (53.9%). There are multiple nationalities living and working in the Cayman Islands. Most of the work permit holders come from Jamaica (15236), the Philippines (5977), the United Kingdom (2053), India (1996), Canada (1,213), and Honduras (1193). Approximately ninety-seven per cent of the people residing on the Cayman Islands live in Grand Cayman, with many of them living in George Town (50.6 %), the most populous of the five districts of Grand Cayman (The Economics and Statistics Office, 2024).

There are several government and private schools across the islands. The education system has a mix of British, American and Caribbean influences, contributing to the uniqueness of this context.

1.2.2 The Study Institution and Education Context

The study institution is in Georgetown and has a student population of 1425 in 2023, with students taking certificate, associate, bachelor's and master's degrees as well as technical vocational, continuing education and pre-college courses (The Economics and Statistics Office, 2024). There are no sixth form options within the government schools for students after they have completed year 11. Some students attend private sixth forms for an additional 2 years, while others go to government-based institutions to retake the secondary exams they did not pass. Other students with the required prerequisites can enrol in the Year 12 Dual Enrolment (DE) programme, where they take university-level classes.

1.2.3 The Dual Enrolment Programme

The dual enrolment (DE) programme is one year long and is an alternative to the two-year 6th form programme, which is part of the education system in the Caribbean and the United Kingdom. As part of the DE programme, students can select an undergraduate plan as their year-12 option, introducing them to higher education and university life. After completing year 12 in the dual enrolment programme, students may continue in their chosen programme with the credits they acquired from the DE programme going towards their associate's or bachelor's degree.

The DE programme comprises compulsory Mathematics and English courses and a college survival course. In addition, students choose a degree path from options such as Engineering Technology, Environmental Science and Biology, Chemistry and Biology and Premedical Studies.

For the interdisciplinary courses, such as Engineering and Chemistry, students are expected to have the requisite level of mathematics. To get on the dual enrolment programme, students must have at least 5 GCSE level (or equivalent) passes, including passes in Mathematics and English, although some students get on the programme without the prerequisite and are required to pass the mathematics and/or English at the next sitting the following year. As mentioned above, students do compulsory mathematics in the DE programme.

1.2.4 Mathematics Challenges in the Interdisciplinary Classroom

Despite the programme's prerequisites and a compulsory Mathematics course, many students still struggle to translate their mathematics knowledge into Chemistry and Engineering, for example.

Students experiencing challenges in the interdisciplinary classroom are not limited to DE students. Some students taking the same course as DE students also face challenges. Usually, these non-DE students range in age from seventeen to sixty years old and are in the classroom with the DE students.

So, students from various academic backgrounds face challenges in the interdisciplinary classroom, whether DE or non-DE students, Chemistry or Engineering students. This poses a problem for the instructors as they do not do mathematics tuition in the chemistry or engineering classroom. This also emphasises the need for an innovative intervention to mitigate the challenges students encounter in their classrooms.

This issue is institution-wide, and some instructors are concerned. Two chemistry instructors contacted me requesting that I assist and offer additional support within their classrooms to help students translate mathematics into chemistry. I also spoke to an engineering instructor who confirmed that he faces similar interdisciplinary struggles in his classroom.

There are many potential reasons why students are struggling with mathematics in their interdisciplinary classrooms. For example:

There is a historically low mathematics pass rate in the region, and some students admitted to the dual enrolment programme have not passed their mathematics examination at the secondary level. Between 2003 and 2019, the mathematics pass rate in the Caribbean secondary level exit examination remained below 50% except for 2 years, where the pass rate was 50% and 57% (Caribbean Examinations Council, 2020). Specifically, in 2022, in the May/June sitting of the exam, only 37% of the 66,347 students who took the mathematics examination throughout the Caribbean passed the examination. The mean score of the students was 38.1% (Caribbean Examinations Council, 2022). For context, 64.9% of students in the U.K. passed the equivalent General Certificate of Secondary Education (GCSE) exam in 2022. In fact, the pass rate for the GCSE mathematics exam in the U.K. has been consistently above 56.4% since 2008, which reflects a higher pass rate than in the Caribbean (https://analytics.ofqual.gov.uk/apps/GCSE/Outcomes/).

Some students who passed their mathematics exit examination may have passed with a low grade, so their mathematical knowledge, comprehension and reasoning may be average. Overall, in 2002, students' scores for the three assessed profiles for mathematics were as follows: knowledge (42.19%), comprehension (35.73%), and reasoning (31.86%) (Caribbean Examinations Council, 2022). This suggests that students are not demonstrating a satisfactory level of competence in these examinations, which ultimately impacts their performance when they transition into higher education and are required to take mathematics or courses that include mathematics.

Algebra is one of the main areas that students struggle with. The 2019 examiner's report from the Caribbean Examination Council (CXC), relating to an algebra question, said this: "Performance on this question was less than satisfactory. All candidates attempted this question and 0.56 per cent of them earned the maximum available mark. The mean mark was 1.52 out of 9." (Caribbean Examinations Council, 2020). Many of the areas of Mathematics that apply to disciplines such as chemistry and engineering are underpinned by algebraic principles. For example, transposing chemical formulae or calculating using scientific notation.

Some students may have passed their mathematics with a high grade, but they do not remember the content they learnt, or they do not know how to translate it to other disciplines, so in instances like these, a review of relevant mathematics content would complement the learning process.

Students are experiencing challenges in the classroom, and the reason behind it may be one or a combination of factors. Whatever the reason, a solution is needed that is capable of mitigating poor performance and helping students bridge the knowledge gaps they now face.

As mentioned above, DE students must have a mathematics pass in the secondary exit examination to be admitted to the programme. However, exceptions are made for some students admitted to the programme without the requisite mathematics pass. Despite some students having the required prerequisite mathematics pass, many students still struggle with Mat 100, the compulsory DE course, and their respective interdisciplinary undergraduate plans, such as chemistry and engineering.

Therefore, something is needed to bring across mathematics to these students, in a way that engages them, boosts their competence and motivates them to learn. How students experience learning is important, and careful consideration and execution of a sound strategy may augment student learning.

1.2.5 Competition in Context

Competition plays a significant role in various aspects of Caribbean life. For example, it is very common across the Caribbean to see people playing games such as dominoes, cards, ludo or checkers at shops or outside someone's home in a social setting. I grew up in Jamaica doing this and have seen it in Trinidad and Tobago, Grenada and the Cayman Islands.

In another instance of the display of the vibrant competitive spirit in this region, it is not uncommon to see hundreds of people gathered in a town centre or town hall to cheer on our Olympic participants, for example when hundreds of people gathered in Half-way Tree, Jamaica, in 2016 to witness Usain Bolt make athletic history, armed with pot covers and various other make-shift musical instruments to celebrate victory (Half-Way Tree electrified as Jamaica celebrates Bolt's third 100m Olympic gold | Lead Stories | Jamaica Gleaner) or when Jordan Crooks of the Cayman Islands made it to the 50m Freestyle final in Paris 2024 Olympics, hundreds gathered in a townhall to watch the performance and support him (Emotional scenes as Cayman reacts to Jordan Crooks' historic swim - Cayman Compass). These examples demonstrate our dedication and passion towards competition in the region.

Competition is also evident in our education system. For example, the leaderboard plays an important role in the education system in this region. In some schools, students are placed on leaderboards based on their academic performance and rewarded for top placements, motivating them to be at the top. This has been around for a very long time. I remember being placed on leaderboards according to academic performance during the 80s and 90s, during my primary and secondary school.

Competition is evident at all levels of the education system across many Caribbean islands. For example, at the primary level, when students are transitioning from primary to secondary, they take a primary exit examination, and the school that they eventually attend is based on their overall score in these exams. In Trinidad and Tobago, the students take the Secondary Entrance Examination (SEA), or in Jamaica, they take the Primary Exit Profile (PEP); both exams are very competitive, and students are placed in secondary schools based on their performance in these exams. Students scoring high overall percentages would be allowed a place in a 'top' school, while those with lower percentages go to the other secondary schools that are not always considered the best option regarding academic prowess. It is very competitive to get into the top schools, and students must work very hard preparing for these exams to get a place in the school of their choice (the first choice is usually a 'top' school). Students' names and the school they have passed for are published online. The top students are notified and acknowledged, and sometimes even give interviews on television or in the newspaper, telling of their success. It is a big deal!

Although many Caribbean islands have this kind of set-up for students transitioning into secondary schools, the Cayman Islands does not have a primary exit examination that determines which secondary school students go to after they leave primary education. Students either go to one of two government secondary schools in Grand Cayman or a private school.

At the end of secondary school, many students across the Caribbean, including the Cayman Islands, take Caribbean Examination Council exams. While students and institutions choose which exams they take, the exams are standardised, and so all students take the same mathematics examination or the same biology exams, irrespective of the island they are on. Top students across the islands are celebrated locally and across the region, further emphasising the core competitive elements of our education system in the Caribbean region.

Given the history of games and competition in the Caribbean lived experience, the success associated with game-based learning at various levels of the education system worldwide indicated by research and positive responses from students from my classroom experience, mathematics game-based learning appeared to be a promising pedagogical approach that could capitalize on the inherent competitive elements within the education system to enhance students experience, engagement and learning outcomes.

1.2.6 Summary of the Research Context

In conclusion, this section summarised the research context, including the study location and institution, with emphasis on the dual-enrolment programme, which is a non-typical year 12 alternative for students leaving secondary school. This section also summarises the challenges in the interdisciplinary classroom in the study institution and highlights the role of competition in the region and its prevalence in the education system.

1.3 Statement of the Problem

By carefully considering the historically poor performance of Caribbean students in their secondary exit mathematics examination, as well as reviewing literature about the success of GBL in the mathematics classroom and observing students' reactions when I incorporated GBL into my teaching practice, it was decided that an intervention was necessary to investigate the impact of game-based learning in my context especially since there was a gap in the GBL research where the Caribbean was concerned.

Technology use in the classroom has increased in recent years. Still, as it pertains to digital game-based learning in the mathematics classroom at the higher education level, its use is lagging. Geiger et al. (2012) suggest that internationally, there have been various research (such as Confrey et al., 2010; Hoyles et al., 2010; Jones et al., 2010) geared toward modeling virtual learning environment blueprinted to stimulate specified facets of mathematics learning; however, there is very little research available by authors in the region even though it is agreed that the status of mathematics education in the region is unsatisfactory (Ogunkola, 2012).

There are several implications associated with conducting this intervention, including discovering evidence-based approaches (instructors), pedagogical implications for curriculum developers, planning and development insights for all stakeholders, and benefits to the current and future students. This investigation, including its approach, is particularly pivotal as it involves the student stakeholders in the evaluation process. According to Saunders (2006), an evaluation is a means of allowing the disadvantaged and disenfranchised to articulate their views, which might, in turn, have a relationship with policy implementation. In this instance, this intervention can potentially give students a say in the courses that are developed for them.

1.4 Theoretical Frameworks

The overarching objective of this research is to explore the impact of a mathematics game-based intervention in a Caribbean HE setting. Notably, the research questions (which are discussed below in section 1.5) aim to investigate students' academic outcomes and provide insight into their point of view after the GBL classroom experience. The research questions are investigated through the lens of self-determination (SDT) and flow theory.

The self-determination theory (SDT) (Jalil et al., 2020; Chan et al., 2019; Tobon et al., 2020; Zainuddin et al., 2018) is a theory of human motivation that stipulates that people have three basic psychological needs: autonomy, competence, and relatedness. The theory proposes that humans experience higher psychological satisfaction when these three basic needs are realised (Chiu, 2022; Tyack & Mekler, 2020; Grasse et al., 2022). Learning environments that facilitate SDT can prompt student motivation and engagement (Chiu, 2022; Tyack & Mekler, 2020), contributing to their overall competence and learning experience.

Csikszentmihalyi (1975) describes flow as a 'wholistic sensation present when we act with total involvement. It is the kind of feeling after which one nostalgically says: "that was fun," or "that was enjoyable" (p. 43). In the context of GBL, flow is used to explain the player's psychological state (Bitrián et al., 2020). During gameplay, players can experience flow when they become totally concentrated and immersed in the game and do not acknowledge the passing time because of the game activity. In this state, players can perform at their optimum as they are totally focused on the game they are playing (Almeida & Buzardy, 2019); therefore, flow also contributes to competence and well-being in the classroom.

1.5 Research Questions

This section describes the four research questions, which are referred to as RQ 1, RQ 2, RQ 3, and RQ 4. These descriptions provide an overview of the research questions and the data collection instrument, as well as a brief mention of the theoretical framework.

RQ 1- To what extent does mathematics game-based learning (GBL) impact students' academic performance? This question aims to determine the extent of the impact of the GBL intervention on students' academic performance. In other words, did the intervention result in a meaningful change in the students' academic performance? Was the impact statistically significant? How does their final score compare to that of previous cohorts? These questions were answered using pretest and posttest instruments, and the grades of the students of the intervention cohort were observed and compared to the grades of students of previous cohorts.

RQ 2 - What are students' perceived competence, relatedness, and autonomy when game-based learning is used in their classroom? The central focus of this question is to explore GBL through the lens of the SDT and see how the students' perceptions of their experiences compare to the theoretical framework and existing literature. The research instruments illuminate questions such as: How competent did the students feel? Did the intervention stimulate any feelings of relatedness? Did the students experience autonomy during the GBL intervention? Likert-type questions on an agreement scale provided an overview of students' perceived competence, relatedness, and autonomy, and open-ended questions and focus groups delved further to hear the students' voices regarding their perceptions of their experiences. This gives an impression of how well the GBL environment satisfies the three basic psychological needs.

RQ 3 - What are students' learning experiences of flow? This question explores the intricate relationship between students' GBL experience and flow. Flow is indeed a complex concept, and several variables must be in alignment to achieve this state. Likert-type questions on an agreement scale, open-ended questions, and focus groups were used to determine students' perceptions of flow. The research instruments helped to elucidate answers to questions surrounding flow, such as: Did the students experience flow during the GBL experience? Did they enjoy the intervention? If they did, to what extent? If they did not, what are the possible reasons?

RQ 4 - What are students' perceptions of the benefits and challenges of mathematics GBL in their course? This question is centred around exploring the students' perceptions of the benefits and challenges of a GBL intervention in their classroom. Students reflected on their experience and provided an overview of what went well and what did not go so well. This kind of reflection is important as it can provide information that can lead to future investigations and inform various stakeholders, including GBL classroom practitioners.

1.6 Overview of the Methodology

This is a convergent mixed-method educational research. A mixed methods approach involves mixing quantitative and qualitative methods (Creswell, 2018). This method was chosen as it provides a balanced overview to answer the research questions adequately.

The quantitative data that were collected are students' pretest and posttest scores (N=39) and their final course grades (N=43). The final course grades of three previous cohorts (N=23, N=27, N=31) on the same courses as the intervention courses were also obtained and used for comparison purposes. The qualitative data collected were from questionnaires (N=38) and focus groups (N=32).

The quantitative and qualitative data were collected at approximately the same time; therefore, this is considered convergent mixed methods research (Creswell, 2018).

In this study, it is possible to see me as an 'insider' as I work in the study institution; I delivered the mathematics review at the beginning of the intervention, marked the pretest and posttests, and analysed and interpreted the data. My position as an insider researcher adds value to the research process. I acknowledge the potential for researcher bias (Fleming, 2018); however, to mitigate this, a second marker was used for the pretests and posttests, and another faculty member conducted the focus group interviews and distributed links for the questionnaire. These steps not only help to mitigate biases but also add to the validity and reliability of the research process.

The research was conducted through a pragmatic lens. In this philosophical perspective, 'researchers emphasise the research problem and question and use all approaches available to understand the problem' (Creswell, 2018, p. 48).

1.7 Contribution and Significance

To the best of my knowledge, no mixed methods study exploring the impact of mathematics GBL at the HE level takes an interdisciplinary (mathematics and chemistry) approach through the combined lens of the SDT and flow theory.

The findings of this study can, therefore, contribute to the wider game-based learning discourse, specifically to HE mathematics game-based learning under the lens of SDT and flow. The findings can then be used to inform SDT and flow theory and classroom practices worldwide. Stakeholders can gain insights and make evidence-based policy decisions relating to HE mathematics classroom pedagogies, which may even be translated to other educational levels. These findings also have implications for the student stakeholders, as they are set to benefit from a learning environment that has the potential to improve their competence in a fun and engaging way.

A more detailed discussion of the significance of this study is provided in the discussion chapter, section 5.4.

1.8 Structure of the Thesis

This thesis has five chapters: introduction, literature review, methodology, results and findings, discussion, and conclusion.

Chapter 1 (this chapter) gives a general overview of the research, including the aim of the study, the problem statement, the methodology overview, the thesis structure, and the researcher's personal motivation.

Chapter 2 provides a literature review of the themes central to the thesis. This includes details of GBL in a HE setting, a look into HE mathematics education, interdisciplinary approaches to mathematics teaching and learning at the HE level, use of technology in the classroom, game elements, and their impact on teaching and learning. This discourse of this chapter also explains the theoretical underpinnings (SDT and Flow) guiding the study. The literature review chapter concludes with the benefits and challenges of mathematics GBL and highlights the research gaps identified from the review of the literature.

Chapter 3 explains the methods and instruments used for data collection and analyses, justifying the respective choices while ensuring the options are valid and reliable. This section also gives details of the study participants and sampling methods. Ethical considerations, including permission, informed consent, privacy, and data storage, are also included in this section.

Chapter 4 presents the results from all the data collection methods using tables, graphs, summaries, and overviews. The data were also analysed using various techniques, including t-test, Analysis of variance (ANOVA), descriptive statistics, normality tests, tests for skewness and kurtosis, and reflexive thematic analyses (RTA).

Chapter 5 summarises the findings and provides an in-depth discussion of the results. The discussion involves juxtaposing the findings with current literature, comparing and contrasting, and answering the research questions. Implications of the research and suggestions for future research are also discussed. The limitations of the study are highlighted in this section.

1.9 Personal Motivation

I have always been enthusiastic about teaching and learning. In the early nineties, while I was still a teenager, I spearheaded a couple of teaching and learning initiatives with the hope that they would benefit people in my little community in Jamaica. For one, I facilitated a summer school programme in the community that ran several summers before I went to university. I also helped two adult women in the community to prepare for their mathematics pre-requisite examination, which they needed to pursue their teaching career. Both went on to have careers in teaching after passing their mathematics exams.

I have worked at the primary, secondary, and tertiary levels as an educator. The experience at the various levels gives me a holistic view of the progression of teaching and learning at the various education levels. My teaching experience, coupled with my own experience as a student, gives me a good insight into various aspects of teaching and learning that may benefit this research process.

More specifically, to this research, I have been a mathematics lecturer at the HE level for over 16 years. Over the years, I have always been interested in pursuing academic research into mathematics teaching and learning; in particular, I wanted to investigate a method that brought enjoyment, competence, confidence, motivation, engagement, and overall student well-being to the classroom while students learn, especially in an area like mathematics where students have a negative perception of the subject and are not motivated to learn it.

During this PhD, I decided to explore mathematics GBL in a Caribbean undergraduate chemistry classroom with the hope that my findings will benefit not only my classroom and institution but also provide insights to complement future research efforts and teaching and learning worldwide.

1.10 Concluding Remarks

In this chapter, I provided an overview of the aim of the research and stated the rationale for undertaking it. I provided a statement of the research problem, discussed the research questions, and gave a brief overview of the methodology. I organised the study in chronological order and provided a background of my experience and suitability to conduct research of this nature. In the next chapter, I will discuss the literature surrounding this GBL intervention to provide the foundation on which the intervention was built.

2 Literature Review

2.1 Literature Selection

This literature review uses an extensive approach, combining the thoroughness of a systematic review with a scoping narrative review. In this section, I will provide details of both the systematic literature review and the narrative review.

To map the field of Mathematics game-based learning in higher education, an initial systematic review was conducted using the eight key steps suggested by Xiao and Watson (2019). The literature selection for the systematic review had a few specifications to ensure a thorough exploration of the current literature relating to Mathematics game-based learning at the higher education level. The specifications are research questions (overarching and focused), key term search, and inclusion and exclusion criteria.

The overarching research question was, "What are the key characteristics of GBL and gamification studies in the context of HE mathematics?" Focused questions were centred around the research methods of the studies, the theories used in them, game elements used, duration of the interventions, areas of mathematics used in GBL, and key benefits and challenges found by the studies. The following inclusion-exclusion criteria (see Table 2.1) were developed to help narrow the search of the articles found and to keep the chosen studies within the scope of the research topic.

Category	Inclusion	Exclusion
Topic	Game-based learning in HE mathematics	Games for entertainment that are not for educational purposes
Level	Higher education level	Kindergarten, primary level, and secondary level studies; studies conducted in the workplace
Academic Discipline	Mathematics (including Mathematics in other disciplines)	All other academic disciplines
Subjects	Student participants, including student teachers	Faculty participants and managerial participants in, for example, a corporate setting
Type of Study	Journal articles that involve a game-based learning intervention	Conceptual papers and game design papers that do not have an evaluation element.
Time	2012- 2022 (May)	Before 2012 and after May 2022
Language	English	All other languages

Table 2. 1 Inclusion and exclusion criteria

The literature search for the systematics review was initially done on The Bielefeld Academic Search Engine (BASE) database based in Bielefeld, Germany; at the time, BASE held over three hundred million documents on its database representing studies from all over the world. Studies on the BASE database can also be found on leading research database platforms, such as WILEY, SCOPUS, IEEE, EBSCO, JSTOR, PubMed, Science Direct, DOAJ, and SAGE. Furthermore, BASE is highly organised, with filters that efficiently generate relevant studies. The BASE search was supplemented with Lancaster One Search, where the article did not have free access.

Key terms involving game-based learning in higher education mathematics were searched, and the following results were obtained (see Table 2.2).

Year of publication	Number of studies on the database from key term search	Studies identified initially	Studies after inclusion/exclusion criteria were applied, duplicates removed
2022 (May)	94	20	0
2021	303	83	8
2020	235	65	4
2019	157	39	7
2018	119	41	1
2017	74	15	3
2016	58	10	2
2015	46	9	0
2014	22	4	1
2013	10	4	0
2012	16	2	1
TOTAL	**1134**	**292**	**27**

Table 2. 2 Results of key term search before and after inclusion-exclusion criteria

After inclusion and exclusion criteria were applied, twenty-seven studies remained. Of the twenty-seven studies, most of them were from 2019-2021, with the most studies from 2021 (8), followed by 2019 (7) and then 2020 (4).

The systematic review suggests that game-based learning was used in several areas of mathematics using various game instruments. There was a positive impact on student engagement and motivation, student collaboration and student centredness, mathematics scaffolding, student satisfaction and enjoyment. It was found that there was a lack of theoretical engagement in the HE mathematics game-based studies. There were also no studies from the Caribbean region at the time of the search.

At this point, I had a good overview of GBL learning in HE mathematics. I wanted to delve into some of the findings and supplemented my initial search with a narrative review. The narrative review phase included journal articles, conference papers, and book chapters. The BASE database was again used to find articles. The BASE search was supplemented with Lancaster One Search, Mendeley Search, Taylor and Francis, and Google Scholar, where the article did not have free access. Research Rabbit (https://researchrabbitapp.com/home) was also used to find related articles on a particular topic.

In this phase, there was no time limit for the searched articles; however, the most relevant studies were conducted between 2000 and 2024. One study was from the 70s, one from the 80s, and two from the 90s. Key term searches for this phase were focused on the themes and headings in this literature review, such as SDT, flow theory, motivation: engagement, mathematics teaching and learning, and mathematics in other disciplines.

In conclusion, the combined phases enable me to understand the field of mathematics game-based learning in higher education, allowing me to identify gaps in the literature and position my own research inquiry.

2.2 Mathematics Teaching and Learning at the Higher Education Level

Mathematics plays a pivotal role in education systems globally. Accordingly, there is ongoing research and discourse among stakeholders concerning the revision and improvement of higher education mathematics education (Lake et al., 2017; Tseng et al., 2013; Croft et al., 2022).

There is no question of the relevance of mathematics teaching and learning at the higher education level, irrespective of whether mathematics is taken as a general education subject or forms part of a student's core degree. After all, mathematics application spans many disciplines and is a main element in all aspects of life (Ernest et al., 2016; Lake et al., 2017).

Notwithstanding its pertinence, there are challenges associated with the teaching and learning of mathematics at the higher education level, and the discourse of stakeholders globally is constantly evolving to remedy the situation.

Lake et al. (2017) conducted a meta-analysis of 74 studies concerning alternative mathematics pedagogy for students with weak mathematics and highlighted some challenges relating to the teaching and learning of higher education mathematics; these include students coming into university with below-par background in mathematics, non-mathematics majors finding mathematics challenging leading to low success rate, students attitudes and preconceived ideas regarding their ability to study mathematics contributing to their anxiety and subsequent failure, students social background, lack of student engagement and interest and self-efficacy issues (Lake et al., 2017). Lake et al. (2017) made some recommendations as to pedagogical approaches that could be used to mitigate some of the challenges, for example, active learning approach, hands-on projects, mentoring programmes, study groups, technology use, diagnostic testing, and one-to-one student assistance.

There is much other research on the failure and success of higher education mathematics teaching and learning; for example, Saha et al. (2024) highlighted in their study that two factors of success in university mathematics were enthusiasm and interest in mathematics content. In another study exploring the ‘Factors influencing first-year students’ success in Mathematics’ (Anthony, 2000), self-motivation was seen by both students and teachers as the most prominent element contributing to student success. Likewise, both saw a lack of self-motivation as a key element for failure in mathematics.

Students and teachers do not always agree on what constitutes success and failure; for example, Saha et al. (2024) reported in their study that teachers attributed students’ failure in mathematics at the higher education level to factors such as inefficient methods used to study, poor subject knowledge and other personal issues faced by the students. On the other hand, the students attributed their failure to unengaging lecture methods and poor course design.

While this may appear to be a 'one blames the other' situation, both parties make valid points and express their views from their personal lens. The failure of students in higher education mathematics is multi-faceted and combines elements relating to the teachers and the students, among other factors. Therefore, students, teachers, and other relevant parties must work together to remedy some of the challenges faced in mathematics teaching and learning.

In a study published in the Journal of Eastern Caribbean Studies in 2015 entitled 'Status of Mathematics Education in the Eastern Caribbean: Issues and Possible Solutions for Teacher Preparation and Support' Leacock2015) reported that:

> *'Even at the undergraduate and graduate levels at the university level, there is concern that only a few students pursue mathematics as their area of study, and students who must take mathematics-related courses to fulfill their degree requirements often do so under duress. Of note is that often, these students are or go on to become mathematics teachers at the primary or secondary level.' (p. 212).*

The above quotation makes several points about the state of university-level mathematics in the Caribbean; firstly, very few students are choosing to pursue mathematics degrees; secondly, those who do have to take some mathematics to fulfil their degree requirements are not happy to do so, and finally, some of these very people are teachers or go on to become teachers. Based on what Leacock (2015) suggests, we are left with an issue where people who do not like mathematics necessarily become mathematics teachers.

This is a concerning issue. Many teacher trainees have negative beliefs about their ability to do and learn mathematics. White et al. (2006) hypothesized that these 'negative beliefs may contribute to negative classroom teaching strategies, which may, in turn, contribute to negative pupil beliefs, attitudes, and performance outcomes. If these pupils then go on to become teachers, a cycle of negativity may be created unless an appropriate intervention breaks the cycle' (White et al., 2006. p. 35).

So, the issues surrounding mathematics teaching and learning are complex and need meticulous and pedagogically sound approaches to the solutions.

2.3 Mathematics in Other Disciplines

Mathematics forms part of many other traditional science disciplines, such as chemistry, biology, physics, and engineering. Mathematics is also present in non-science disciplines and fields such as computer science, defense and security, economics, finance, genetics, and geometric motions, to name a few (Masanja, 2002), as well as fields that interlink mathematics, but its presence is not so obvious such as art and design, languages, history, geography, economics, music, physical education, religious education (Yeasmin et al., 2017).

At the university level, mathematics may be taken as a standalone degree, but it can also be integrated into other courses and form part of their degree plans. For example, in my institution, students pursuing business degrees take calculus for business and probability and statistics, the computer science majors take discrete mathematics, and all students take some element of basic mathematics as part of their general education requirement, irrespective of their degree destination.

To bridge the gap between disciplines, some universities take an interdisciplinary approach where mathematics and science students collaborate on projects (Masanja, 2002). In my institution, I recently collaborated with a chemistry teacher. I offered extra mathematics assistance to the students in their chemistry classroom as part of research where the teacher evaluated their self-efficacy. Another example of interdisciplinary collaboration is a conference I participated in (towards the end of 2022) hosted by the Western Virginia University in the United States of America (USA), which brought together chemistry and mathematics faculty pairs from various USA and Caribbean universities to explore the scholarship of teaching and learning (SOTL) so that participants could bring back this collaborative knowledge and research expertise to their respective universities and colleges. The end goal was to collaborate on a mathematics and chemistry research project, bringing the disciplines together. I participated in this conference as a mathematics faculty member teamed with a chemistry faculty member from my institution. We are working on a collaborative research paper, which we intend to publish soon.

According to Dorier (2010), ‘the structure to teaching institutions, in many cases, makes the collaboration between teachers from different disciplines very difficult’ (Dorier, 2010, p.145). Therefore, collaborative efforts like those of Western Virginia University mentioned above are paramount in creating and fostering that bridge between disciplines.

Many acknowledge and agree with the importance of mathematics as part of an interdisciplinary aspect in their field. Take, for example, a decision by Rochester University in the United States in 1996 to reduce the size of its mathematics faculty. This decision was met with firm protests by mathematicians and scientists.

‘Strong protest statements were made by at least six Nobel laureates, by dozens of members of the 7 National Academy of Sciences, as well as by other leaders in science and industry. The outpouring came from many fields, including biology, chemistry, computer science, economics, geology, mathematics, philosophy, physics, and sociology’ (Masanja, 2002, pp. 7-8).

Interdisciplinary approaches involving mathematics and other subjects are not without their challenges. Dorier (2010) conducted research involving mathematics in other disciplines and found that teachers’ knowledge regarding other subjects was limited, even if it related to their own subjects. Additionally, they reported that ‘Mathematics teachers do not want to get involved in too specialised applications while physics or economics teachers send their students back to their mathematics teacher for explanations on the use of mathematics in their field.’ (Dorier, 2010, p. 147). The consequence of this is that students are accustomed to seeing mathematics and other fields as mutually exclusive elements (Dorier, 2010).

It would be beneficial for educators as well as students to see the relevance of interdisciplinary approaches as this is likely to make mathematics more desirable and accessible while at the same time igniting interest in understanding the significance of mathematics concepts (Dorier, 2010).

More research is needed to make the connection between mathematics and other disciplines more apparent, including research-based teaching resources and new pedagogical approaches (Maass et al., 2019).

In this research, an investigation of mathematics game-based learning in the chemistry classroom contributes not only to the discourse of mathematics GBL but also to research in interdisciplinary approaches to mathematics in other disciplines.

2.3.1 Mathematics in Chemistry

Mathematics is vital for success in Chemistry courses (Neville et al., 2018; Shelton et al., 2023; Williams et al., 2019). In fact, researchers found a correlation between mathematics proficiency and student success in the chemistry classroom (Spencer, 1996; Willis et al., 2022; Powell et al., 2020; Williamson et al., 2020).

Many students enter university who do not have the required level of mathematics proficiency that will enable them to pass their chemistry courses. Recognising that there are gaps in students' mathematical knowledge and understanding of the impact this may have on their learning in the chemistry classroom, some institutions and researchers used various interventions to remedy this problem. For example, the mathematics and chemistry departments of Colorado State University in the United States collaborated and executed a Mathematics for Chemist course aimed at preparing students with the requisite mathematics tools needed for success in their physical chemistry course (Neville et al., 2018). In other examples, researchers used supplemental mathematics review sessions and peer learning techniques to boost students' mathematical knowledge deemed necessary for their success in chemistry (Williamson et al., 2020).

These mathematics intervention efforts can empower chemistry students and set them up for success rather than struggling with the mathematics that is a part of the chemistry they are taking.

2.3.2 The MUST Test

The MUST (Math-Up Skills Test) is commonly used in chemistry research, particularly for the assessment of students' mathematics competencies when starting their chemistry course (Shelton et al., 2023; Williamson et al., 2020; Powell et al., 2020).

Studies show that the MUST test is a good instrument to identify students who will succeed in their lower-level chemistry course, and hence, this instrument may be used as a good tool to identify students who are at risk of getting low grades in their chemistry course (Shelton et al., 2023; Powell et al., 2020).

The original MUST tests contained sixteen questions, but four fraction questions were subsequently added to make it a twenty-question quiz (Mason & Shelton, 2023). The MUST quizzes are fifteen minutes long and can be completed with or without a calculator.

Two mathematics professors validated the sixteen-question quiz. The MUST tests were statistically proven to be highly reliable (KR-21 = 0.821), with no statistical differences between the versions (Petros et al., 2018). The KR-21 (Kuder-Richardson Formula 21) is a reliability measure ranging from 0 to 1. Measures above 0.8 to 0.89 are considered good, and above 0.9 is considered excellent (Balasubramanian & Sudha Rani, 2023).

The MUST test has been used to predict students expected grades in their chemistry courses with great accuracy; in fact, it has been shown that higher scores in the MUST tests correlate with higher course averages and lower failure rates (Shelton et al., 2023).

Research involving identifying students' expected outcomes using the MUST test, applying interventions to mitigate the impact of at-risk students, and observing their final grade outcomes can shed light on the impact of interventions on student outcomes. This research combines the MUST test with a game-based intervention conducted using the technology-based platform Kahoot! to determine the impact on students' grades.

In the next section, I will discuss the use of technology in the mathematics classroom and its potential impact on teaching and learning.

2.4 Technology in the Mathematics Classroom

There are opposing viewpoints as to how technology in the classroom supports learning. Eyyam and Yaratan (2014) and Segun and Oluwaseyi (2020) agree that the use of technology in classroom instruction enhances student learning, allowing them to learn more efficaciously. Further, in the technology-infused classroom, learning is more enjoyable and, hence, more attractive as a direct consequence of the students' interactive involvement in the learning process (Eyyam & Yaratan, 2014).

In addition, Rashid and Asghar (2016) posit that since technology can 'facilitate student-student and student-faculty interactions, it may foster engagement and self-directed learning.' (p. 606). Despite the claims by some researchers that technology use in the classroom enhances learning and engagement, Lowther et al. (2008) claimed that a technology-enhanced learning environment produced mixed results for student gains. Considering this contrast, it will be very enlightening to see the outcomes of digital game-based learning in the classroom to see what happens in a Caribbean higher education context.

Digitalisation is omnipresent. This has propelled the transformation of mathematics pedagogy in many ways or at least facilitated the mechanisms for stakeholders to supplement traditional teaching and learning methods and develop new ones (Siew, 2018).

The pertinence of these approaches is indisputable. Take, for example, the COVID-19 pandemic, in which many institutions were forced to move their traditional face-to-face classes to a digitalized modality. The use of technology-based pedagogy, in this instance, helped to facilitate a smoother transition (Mutenga & Marbán, 2020).

Additionally, students' expectations to interact with technology in their courses and in relation to classroom learning have evolved (Gunduz et al., 2020). It is reported that students require a 'more active role in the learning process,' and as such, 'educators should prioritize activities that students can participate in more actively to achieve permanent learning' (Gunduz et al., 2020, p. 1). To develop mathematics education and its technological facilitation, it is necessary to develop research in the field. Bakker et al. (2021) identified future research areas in the field by asking 229 scholars in mathematics from 44 countries across six continents, 'On what themes should research in mathematics education focus in the coming decade?' (p. 2). The results showed that 64% of respondents suggested 'Approaches to teaching' and 22% percent responded 'Technology.' (Some respondents chose both themes). One area that merges both the field of 'approaches to teaching' and 'technology use' is that of incorporating game elements in the classroom. This technological addition to teaching and learning may effect changes in education delivery and encourage reforms in future mathematics education.

In conclusion, integrating technology in the mathematics classroom can promote fun learning and create a dynamic learning environment that fits students' expectations. In the next section, I will discuss GBL and gamification and their role in an educational environment.

2.5 Game-Based Learning and Gamification

Whenever you think of game-based learning, gamification also comes to mind; in fact, some of their elements overlap. Even though there are similarities between GBL and gamification, they are different, with separate definitions. According to Junior et al. (2019, p.3), 'the concepts of GBL and gamification are similar but sufficiently distinct. The first one denotes the adoption of games for educational purposes, and the second the application of gaming mechanisms to global educational interventions.' Krath et al. (2021, p. 2) define GBL as 'the achievement of defined learning outcomes through game content and play and enhancing learning by involving problem-solving spaces and challenges that provide learners, who are also players, with a sense of achievement.' In this study, I adopt a similar understanding of GBL, where I use challenge and problem-solving through gameplay to enhance mathematics learning outcomes. Conversely, gamification is defined as 'the use of digital game design elements in non-game contexts.' (Deterding et al., 2011, p.10).

While GBL and gamification share similarities, this study focuses on GBL as its principles align more closely with the research aims.

Game-based learning has found its way into many classrooms, traversing academic disciplines and educational levels; accordingly, there has been much research across disciplines conducted in this area at various education levels in several countries. For example, Sun et al. (2021) used digital game-based learning as a mathematics scaffolding tool among primary school students in China and secondary school students in Spain diagnosed with dyslexia engaged with GBL to improve their reading processes. They used a game called 'The Legends of Elendor.' In this game, students formed teams with the aim of defeating a virtual villain by surpassing reading challenges (León et al., 2023). Sandrone and Carlson (2021) reported several applications of GBL to undergraduate and graduate medical education. In one instance, a game called 'Neurological Hat Game' was used to teach neurological semiology among medical students in Paris. This involved two teams of students playing against each other, guessing the 'neurological sign or a symptom' featured on the cards from a deck. (Sandrone & Carlson, 2021, p. 2).

Despite, and particularly because of its ubiquity, further research is needed to illuminate and possibly determine the optimal impact of GBL on education. A systematic review of GBL and gamification in Asia conducted by Kennedy and Lee (2018) concluded that researchers should have longer intervention periods when implementing it in the classroom to understand its full impact better. They also found that most of the GBL and gamification interventions were done at the primary level, with science and social studies being the most common academic areas. They reported just one study using GBL and gamification in Mathematics.

Game-based learning and using game elements in the classroom are not new concepts. In my personal experience of points and leaderboards, back in the '80s and '90s, for my primary and secondary education, we were placed on leaderboards on a class basis and on an academic subject basis based on the points you scored on tasks and assessments. Furthermore, a simple Google Scholar search of the key term ‘Game-based learning’ generated studies from the 1950s. What has changed over the last few years is that the number of studies in these areas has dramatically increased with the ubiquity of technology-enhanced learning and with the incidence of the Covid-19 pandemic (Yuniawatika, 2020; Sonsona et al., 2021; Krouska et al., 2022; Mavroudi et al., 2022) as educators sought to provide engaging and motivating online lessons.

Despite the increase in practitioners employing non-traditional techniques such as GBL in classrooms, some educators are averse to changes and prefer to lean toward traditional methods and techniques (Karanezi & Rapti, 2015; Tufail & Mahmood, 2020; Balliu & Belshi, 2017). For example, these are two responses from teacher participants in a study by Karanezi & Rapti (2015) regarding the teachers’ views on traditional teaching methods compared to modern teaching methodologies:

Teacher 1 – ‘I always apply traditional teaching methods, and actually I do not see anything wrong on that. I do not think that modern teaching methodology would give something more to the students.’

Teacher 2 – ‘I don’t think that these modern teaching methodologies are suitable since when these techniques are applied in the classroom, they bring a lot of noisy, and students are not able to listen anything.’ (p. 626)

There are many studies reporting positives outcomes with the implementation of GBL and gamification (Suparlan et al., 2019; Zabala-Vargas et al., 2021; Gil-Doménech & Berbegal-Mirabent, 2019; Shaker et al., 2021; Rosillo & Montes, 2021; Heller et al., 2021; Koparan, 2019; Kaedah et al., 2020; Ting et al., 2019; Marie et al., 2020; Delgado-Gomez et al., 2020). Studies suggest that incorporating game elements in online learning modalities results in increased student productivity, effectiveness, and student motivation (Gündüz & Akkoyunlu, 2020). Gamification adds fun to learning by using, for example, leaderboards, badges, virtual money, progress bars, and points to help keep students motivated to participate in class activities. It is claimed that gamification can ‘encourage non-motivated students to participate more in their learning process and interaction with other students.’ (Ekici, 2021, p. 3329).

Furthermore, notwithstanding the positive results from GBL interventions some educators might not consider it a viable option due to lack of funding and resources needed for implementation (Fogel et al., 2021; Jääskä & Aaltonen, 2022), issues with teacher preparedness (Greipl et al., 2020; Jääskä & Aaltonen, 2022) and accessibility issues (Fogel et al., 2021; Greipl et al., 2020). As suggested by (Gallagher et al., 2022), ‘In order to support mathematics teacher adaptability, leaders need to ensure that the teachers with whom they work have the knowledge and beliefs necessary to thoughtfully adapt their instruction’ (Gallagher et al., 2022, p. 316). The impetus required to propel purposeful change in educators’ opinion and practice in the classroom may very well have to start with the leader stakeholder, for example, in the form of professional development.

Negative impacts of using game elements in the classroom have also been reported (Toda et al., 2018; Almeida et al., 2021). For example, Kwon et al. (2021) assessed the use of gamification as an examination assessment tool and found it to be less effective in this regard, resulting in students achieving significantly lower scores than their control group counterparts. Nevertheless, this is contrary to the result by Marie et al. (2020), who also used a game-based tool in the form of diagnostic and post-test assessment and found the game-based tool to be an acceptable learning tool that was effective in increasing students’ performance in precalculus.

2.5.1 Mathematics Game-based Learning

As mentioned above, game-based learning (GBL) classroom interventions have gained momentum in the last few years. Pertaining to mathematics, more research is needed at the higher education level (Ortiz et al., 2016). Most of the existing research in GBL in the context of mathematics has been conducted at the primary (Yeh et al., 2019; Brezovszky et al., 2019; Yağmur, 2020; Setiawan, 2020; Sun et al., 2021; Karamert &

Vardar; 2021) and secondary (Hamid et al., 2022; Prieto et al., 2019; Rondina & Roble, 2019; Aqilah et al., 2021; Wulanningtyas et al., 2021; Ortiz et al., 2022) level (See Figure 2.1). Many of these studies reported favourable outcomes when GBL was used at these levels. For example, Sun et al. (2021) investigated the use of digital game-based learning (DGBL) as a scaffolding tool to teach integer arithmetic to primary school students and found that the use of game elements had a positive impact on students' perception and learning. On the other hand, Hamid et al. (2022) explored the use of non-digital game-based learning (NDGBL) in teaching and learning isometric transformation to secondary school students. They also reported positive student learning outcomes.

The subject of mathematics is feared by many students in higher education (Itter & Meyers, 2017), and they find understanding several concepts particularly challenging (Nadezhda & Okello, 2010); because of these challenges, their intrinsic motivation toward the subject can be exceptionally low. One way to mitigate this is by using game elements in mathematics learning (Gil-Doménech & Berbegal-Mirabent, 2019). As stated by Csikszentmihalyi (1975), 'Philosophers from Plato to Sartre have remarked that people are most human, whole, free, and creative when they play' (p. 42), so if students play mathematics games in the classroom, they may benefit from positive outcomes such as creativity and feelings of freedom and wholesomeness.

Due to the positive outcomes associated with GBL integration and implementation in teaching and learning, it is not surprising that mathematics practitioners and researchers apply GBL to several mathematics areas. At the higher education level, game-based classroom interventions have been applied to several areas of mathematics, including probability and statistics (Bortot & Coles, 2019; Koparan, 2019; Delgado-Gómez et al., 2020; Shaker et al., 2021).; Wang et al., 2021; Koparan, 2022; Heller & Pogaru, 2021; Rosillo & Montes, 2021; Karakuş & Baki, 2020; Lopes et al., 2017; Goehle & Wagaman, 2016), developmental and college algebra level mathematics (Abdu et al., 2015; Agbonifo et al., 2021; Karakuş & Baki, 2020; Holden, 2016.; Goehle & Wagaman, 2016), calculus (Gil-Doménech & Berbegal-Mirabent, 2019; Suparlan et al., 2019; Ting et al., 2019; Rosillo & Montes, 2021; Zabala-Vargas et al., 2021; Goehle & Wagaman, 2016), pre-calculus (Marie et al., 2020), logic (De Troyer et al., 2019), mathematics of economics (Nurul Hasana, 2018), mathematics for ICT (Perera et al., 2017), medication calculation (Foss et al., 2014) and trigonometry for carpentry (Pedersen et al., 2012). Despite the use of mathematics GBL in several interdisciplinary areas, there appears to be a shortfall in STEM application. Of the 27 studies in the initial systematic review, none of them represented the use of mathematics GBL in a chemistry classroom.

GBL addition to various mathematics areas may transform how mathematics is perceived by students and impact their learning experience and academic outcomes not only in mathematics as a single discipline but also in interdisciplinary mathematics areas.

Many researchers report positive results of the implementation of game-based learning and gamification in higher education mathematics. Key outcomes include: enhanced collaboration and student-centredness (Gil-Doménech & Berbegal-Mirabent, 2019; Suparlan et al., 2019; Zabala-Vargas et al., 2021), an increase in student motivation (Gil-Doménech & Berbegal-Mirabent, 2019; Shaker et al., 2021; Rosillo & Montes, 2021) improvement in engagement (Shaker et al., 2021; Heller et al., 2021), student enjoyment (Koparan, 2019; Kaedah et al., 2020), an increased understanding of mathematics concept and content resulting in improvement in student performance (Gil-Doménech & Berbegal-Mirabent, 2019; Ting et al., 2019; Marie et al., 2020) and overall satisfaction (Gil-Doménech & Berbegal-Mirabent, 2019; Delgado-Gomez et al., 2020). These positive outcomes span several areas of mathematics, including calculus (Zabala-Vargas et al., 2021; Ting et al., 2019), statistics (Wang et al., 2021; Heller et al., 2021; Delgado-Gomez et al., 2020; Shaker et al., 2021) probability (Koparan, 2019, 2021) and logic (De Troyer et al., 2019).

2.5.2 Types of Games Used in Higher Education Mathematics GBL

A review of relevant literature shows that many games are used in the mathematics classroom to facilitate game-based learning. Some games used were traditional ones; for example, Suparlan et al. (2019) used a monopoly-based board game, and students had a positive perception of the intervention. In another instance, rock-paper-scissors was used in a study, and this garnered positive student feedback (Bortot & Coles, 2019.; Koparan, 2019).

Other games played in the classroom to facilitate game-based learning included escape rooms. An escape room is a game where players must ‘escape’ from a room filled with challenges they must solve in a given time limit to win (escape) (Wiemker et al., 2015). Escape rooms are an interesting gaming method to motivate students. In Rosillo & Montes (2021), the researchers used the escape room to teach statistics and calculus to pharmacy and nursing students. The escape room was ‘based on the search for a scientist who is fleeing with the COVID-19 vaccine around the world, and the students had to find the vaccine by passing tests and missions related to mathematics’ (Rosillo & Montes, 2021).

Some games were physical board games (Suparlan et al., 2019; Heller & Pogaru, 2021) while others used digital games that the student had to play on their technology device on games platform such as Kahoot (Ting et al., 2019; Kaedah et al., 2020; Shaker et al., 2021; Zabala-Vargas et al., 2021) and Socrative (Kaedah et al., 2020; Zabala-Vargas et al., 2021). Kahoot and Socrative are online quizzing platforms that reported positive outcomes when applied to higher education mathematics, such as enjoyment, motivation, engagement, and an increase in learning (Ting et al., 2019; Shaker et al., 2021); Kaedah et al., 2020); Zabala-Vargas, 2021).

While many researchers used existing games and game platforms, others designed and tested game applications to teach a particular mathematics course (Abdu et al., 2015; De Troyer et al., 2019; Wang et al., 2021).

2.6 Theoretical Background in GBL

To map GBL, it is important to understand which theories are commonly applied and what they help illuminate. There is a need for theoretical comprehension surrounding the psychological underpinning of gamification (Krath et al., 2021). A systematic review of theories in GBL and gamification research conducted by Krath et al. (2021)

uncovered 118 different theories used by researchers. The three most common theories were self-determination theory (SDT), flow theory and experiential learning theory (ELT) (Krath et al., 2021)

Overall, theoretical application in GBL and gamification research may be categorised into the following domains: motivation and affect behaviour and learning (Krath et al., 2021).

Surprisingly, despite the apparent relevance of identifying the fundamental principles that can explain how GBL works in the context of higher education mathematics, from my literature research, it was found that many researchers did not anchor their studies using any theoretical foundation at all, this means that there is a gap in the application of theoretical foundation to GBL research in higher education mathematics. This lack of research engagement with theory means there is a need to apply theory more in higher education mathematics GBL research, as that will help explain student experiences and learning. Furthermore, there is a lack of theorisation through different lenses, for example, sociological (e.g., interactional), interpretive (e.g., semiotics), and media-based (media theories, multimodality).

In exploring students' experiences within a mathematics game-based learning environment, this study draws on two complementary psychological frameworks: Self-Determination Theory (SDT) (Deci & Ryan, 1985, 2000) and Flow Theory (Csikszentmihalyi, 1990). These theories were selected for their strong alignment with the study's focus on students' perceived enjoyment, competence, and engagement. SDT provides a robust foundation for understanding the motivational mechanisms that support learning, particularly the role of autonomy, competence, and relatedness in fostering intrinsic motivation. SDT offers a powerful lens for examining how game features may satisfy or frustrate these psychological needs. Flow Theory, by contrast, focuses on the experiential quality of engagement, describing a state of optimal experience characterised by deep concentration, a sense of control, and intrinsic enjoyment. SDT and Flow Theory are very well suited to capturing the dimensions of learner motivation and engagement that are central to game-based learning. Together, they provide a comprehensive account of how and why students engage in a game-based learning environment.

I chose SDT and flow as the theoretical frameworks for this study, as they allowed me to capture the key elements that are the focus of this research. They were seen as appropriate and sufficient to provide sound theoretical grounding, offering structure and direction to the research.

Furthermore, both theoretical frameworks have been widely applied in game-based learning research, attesting to their theoretical rigour and appropriateness. Additionally, despite the ubiquity of SDT and flow theory in game-based research, no studies were identified combining both theories in mathematics game-based research, and I was interested in exploring the complementary impact of SDT and flow theory in the mathematics classroom to see how their integration could help to interpret how mathematics games work in the Caribbean classroom.

In the section below, I delve further into the theoretical frameworks used in this research. This helps to illuminate the status of the theoretical underpinnings of mathematics game elements as they relate to these theories.

2.6.1 Self-determination Theory (SDT)

The self-determination theory (SDT) (Jalil et al., 2020; Chan et al., 2019; Tobon et al., 2020; Zainuddin et al., 2018) is a theory of human motivation that stipulates that people have three basic psychological needs: autonomy, competence, and relatedness. The theory proposes that humans experience higher psychological satisfaction when these three basic needs are realised (Chiu, 2022; Tyack & Mekler, 2020; Grasse et al., 2022).

SDT is often used in education and game-based research (Chiu, 2022; Tyack & Mekler, 2020; Grasse et al., 2022; Kayser et al., 2021; Chan et al., 2019; Tobon et al., 2020; Zainuddin, 2018; Azadvar & Canossa, 2018; Farrell & Moffat, 2014; Proulx & Romero, 2016). Pedagogical design incorporating SDT elements can prompt student motivation and engagement (Chiu, 2022; Tyack & Mekler, 2020), so it is not surprising that this theory is one of the most common in game-based learning research.

As stated by Krath et al. (2021), SDT's use in game research is either aimed at 'deriving implications for game design' or 'at measuring whether an intervention increases the perceived competence, relatedness, and autonomy' of learners (Krath et al., 2021, p. 21). Essentially, 'SDT's analysis of educational settings is primarily focused on the extent to which they meet or frustrate these basic needs' (Deci & Ryan, 2020, p. 1).

2.6.2 Student Motivation

When a person is motivated, he/she is naturally inspired to do something; on the other hand, an unmotivated person is uninspired to act (Ryan & Deci, 2000). You can see why student motivation would be paramount to various education stakeholders. If students are not motivated to learn, it can negatively impact their academic experience.

Many theories of motivation treat motivation as a unitary concept, suggesting that either a person has very little motivation or is highly motivated (Ryan & Deci, 2000). This theoretical take is an oversimplification and does not truly reflect the complexities involved in motivation. For example, it does not consider someone who may be moderately motivated (more than just a little motivation) or, someone who is experiencing variations in their levels of motivation, or even someone whose motivation changes based on factors such as the task at hand, the environment they are in and the method of delivery of the task.

Motivation as a unitary concept is not the only interpretation of motivation. Ryan and Deci (2000) suggest that not only can motivation be quantified based on the amount of it a person has or does not have, but it may also be categorized based on the type of motivation. They proposed a basic categorization of motivation as intrinsic and extrinsic. Intrinsic motivation refers to an individual doing something because they are genuinely interested in it or enjoy doing it. In contrast, extrinsic motivation refers to an individual doing something because they are driven to do it by external factors such as rewards and pressure. This more encompassing view provides a better understanding of what drives motivation and informs potential approaches to bring about and sustain it.

Intrinsic motivation can lead to high-impact learning and creative expression. However, it appears to decrease as we grow past the early years and are expected to conform to the social norms and stipulations that are not necessarily inherently interesting. 'In schools, for example, it appears that intrinsic motivation becomes weaker with each advancing grade' (Ryan & Deci, 2000, p.60).

Extrinsic motivation was traditionally viewed as lacking when compared to intrinsic motivation, but in a paper by Ryan and Deci (2000), they placed extrinsic motivation on a continuum and suggested that it can engender not only negative but also positive outcomes depending on the level of autonomy or self-determination involved. I concur that the outcome of extrinsic motivation is dependent on the driving forces behind it. For example, if extrinsic motivation comes about due to peer pressure, this might induce emotions that will negatively impact the experience and overall outcome.

Understanding the intricacies of extrinsic motivation is therefore pivotal, especially in an environment of reduced intrinsic motivation, which is the case with many educational environments, as many students come to learn, not because they are necessarily inherently interested in the taught content or institution, but because they are required and expected to do so. In the two sections that follow, I will explore motivation through the lens of the SDT to see the role that autonomy, competence, and relatedness play in motivation.

2.6.3 Motivation and the SDT

SDT delves into motivation and elucidates some of its intricate elements. For one, SDT is 'organized around three sets of motivational processes-intrinsic, extrinsic, and amotivational-and their relationships to the concept of self-determination.' (Ryan & Deci, 1985, p. 131). Furthermore, as stated above, intrinsic motivation can lead to 'high-quality learning and creativity' (Ryan & Deci, 2000, p. 60). It is, therefore, safe to assume that a classroom full of intrinsically motivated students is perhaps every educator’s dream, but the reality is that classroom environments are populated with students who are not always motivated out of sheer eagerness and interest. Therefore, understanding what inhibits and catalyses motivation would be useful for teaching and learning to inform pedagogical strategies that will succeed.

Embedded in SDT are the concepts of internalization and integration. ‘Internalization is the process of taking in a value or regulation, and integration is the process by which individuals more fully transform the regulation into their own so that it will emanate from their sense of self.’ Internalisation places one’s motivation for behaviour on a scale where it can range from ‘amotivation or unwillingness, to passive compliance, to active personal commitment.” (Ryan & Deci, 2000, p. 60) (see Figure 2.1). SDT further specifies that there are several types of extrinsic motivation on such a scale. For example, one extrinsically motivated person may perform a task because they feel forced to do it by some external force, in which case there may be negative emotions associated with having to do the task, while another may approach the task with an attitude of eagerness because they see value in the activity or what the activity may result in. Both were extrinsically motivated to begin with, but each had a different attitude towards doing the task. Their level of autonomy varied, where the former felt forced and may have feelings of resentment and indifference, and the latter, having been more accepting, felt more self-regulated where the activity was concerned (Ryan & Deci, 2000).

Ryan & Deci (2000) categorises extrinsic motivation into four groups. The first two are external regulation (this is where the person is being compliant and does an activity due to an external force perhaps encouraged by a reward of some sort) and introjected regulation (this is where the person is also being compliant and does the activity but only because they feel pressured and would otherwise feel guilt and/or apprehension). In both cases, the person feels controlled and is forced to do an activity due to a promised reward or to avoid negative emotions. The third type of extrinsic motivation, which involves a bit more autonomy or self-determination, is called identification (this is where the person does the activity and does not feel forced to do it as they see the value of doing it). The fourth type is called integrated regulation (this is where the activity has been attributed to the self and is highly autonomous and self-determined).

The third and fourth examples of extrinsic motivation involve some element of autonomy, and the person involved experiences internalization.

Integrated regulation experiences the highest level of internalization. Though different, integrated regulation parallels intrinsic motivation and is the closest match of the different types of extrinsic motivation in that they are both ‘autonomous and unconflicted’ (see Figure 2.1).

In the context of classroom learning, extrinsically motivated students may be gently propelled into action in such a way that the choice to act feels autonomous and self-determined, thus facilitating increased internalization.

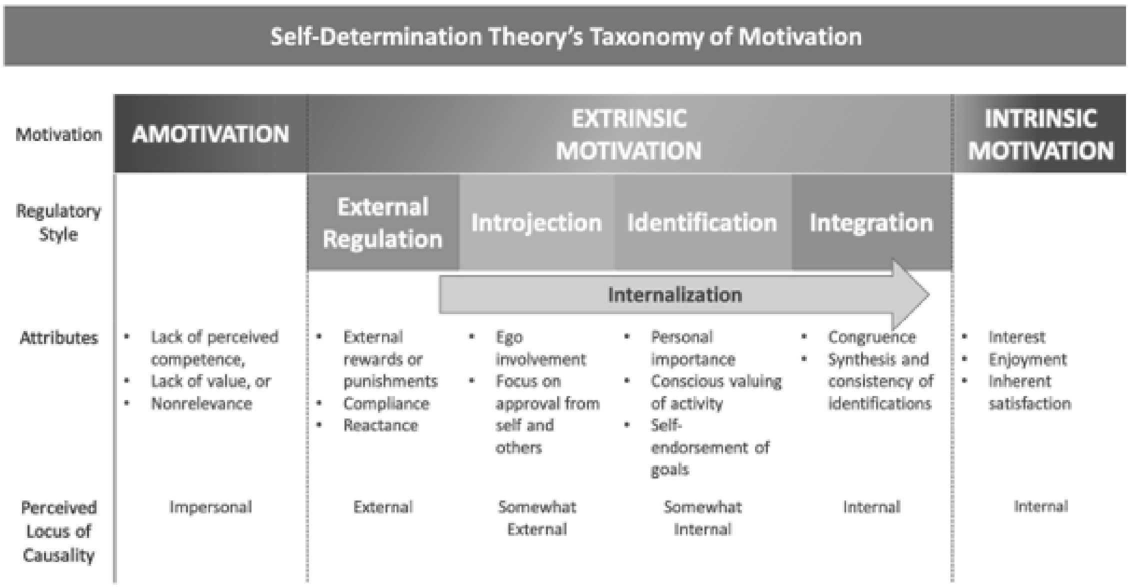

Figure 2. 1 Intrinsic and extrinsic motivation (Adapted from Ryan & Deci, 2000, p.2)

2.6.4 Autonomy, Competence and Relatedness

SDT assumes that humans are naturally inclined to grow and integrate and hence have a propensity towards cognitive development, mastery, and interpersonal connection, though these proclivities are not necessarily automatic and need the right environment for optimality. Support of the basic psychological needs of autonomy, competence, and relatedness can help people achieve optimal growth (Ryan & Deci, 2020).

Autonomy relates to one having a sense of ownership in one's actions. It is complemented by experiences that the person finds interesting and valuable but inhibited by experiences of being controlled externally. Competence refers to the feeling that they can do something well. Efficiently organised surroundings that facilitate ‘optimal challenges, positive feedback, and opportunities for growth’ are best suited to optimising competence. Relatedness is when someone feels a sense of ‘belonging and connection,’ and shows of respect and care bring about feelings of relatedness (Ryan & Deci, 2020, p.1).

My experience with this research has shown me that the SDT elements; autonomy, competence, and relatedness are important factors that play a significant role in the classroom environment as a whole, but also careful consideration of the elements must be done when introducing classroom interventions, for example, using an inappropriate amount of challenge in a GBL activity or having students take part in activities that do not encourage autonomy, may not have the impactful results you anticipate.

In the next section, I will discuss (in detail) the other theoretical framework used in this research, the flow theory. The flow theory parallels the SDT in some instances. For example, both flow and SDT acknowledge that the right amount of challenges is needed to achieve optimality.

2.6.5 Flow Theory

Flow theory (Almeida & Buzady, 2019; Catal´an et al., 2019; Bitri´an et al., 2020) is also a very common choice among GBL researchers. Krath et al. (2021, p. 21) state that ‘Flow is measured to evaluate gamified interventions and to draw implications for the relationship between flow and behavioral outcomes.’ Hungarian American Prof. Mihaly Csikszentmihalyi is the architect of flow theory (Almeida et al., 2021). Csikszentmihalyi (1975) describes flow as a ‘wholistic sensation present when we act with total involvement. It is the kind of feeling after which one nostalgically says: “that was fun,” or “that was enjoyable” (p. 43).

Flow may be found in many places and activities, for example, an athlete participating in a sporting event, playing a game of chess, a musician performing a piece, reading a good book, talking to a friend, or doing a job you love (Csikszentmihalyi, 1998). These activities have a common denominator during the experience of flow. For flow to happen during an activity, concentration, interest, and enjoyment must occur together. (Shernoff et al., 2003; Hamari & Rowe, 2014).

In the context of GBL, flow is used to explain the player’s psychological state (Bitrián et al., 2020). ‘This mental state is characterized by intense concentration, merging of action and awareness, loss of self-consciousness and a distortion of temporal experience people feel when they act with total involvement’ (Krath et al., 2021, p. 21). During gameplay, players can experience flow when they become totally concentrated and immersed in the game and do not acknowledge the passing time because of the game activity. In this state, players can perform at their optimum as they are totally focused on the game they are playing (Almeida & Buzardy, 2019).

For flow to occur in the first place, there must be a symbiotic balance between the level of challenge being experienced and the skill set available to meet those challenges. If there is a mismatch between the level of challenge and the level of skill, apathy, anxiety, or relaxation may result (Shernoff et al., 2003; Hamari & Rowe, 2014) (see Figure 2.2). However, in a classroom setting, both students and teachers may be able to adjust their respective skills and challenge levels in order to be in a state of flow; for example, a student may ‘rise’ to the challenge, or a teacher may decrease or increase the level of challenge to one more appropriate (Shernoff et al., 2003).

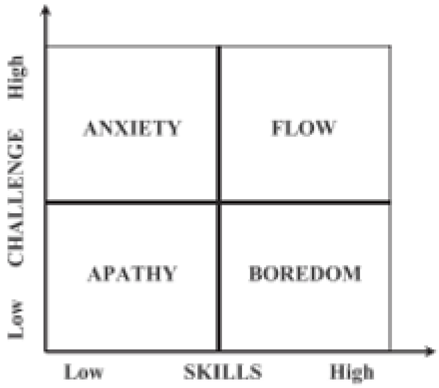

Figure 2. 2 Challenge-skills emotional relationship (Adapted from Bitrián et al., 2020, *p.2)*

2.6.6 Flow and Student Engagement

Student engagement is an ongoing concern for educators as students sometimes feel bored and alienated in their educational setting. This disengagement can contribute to absenteeism, students failing classes, and poor attrition rates (Shernoff et al., 2003).

Shernoff et al. (2003) state that student engagement is influenced by several factors, namely: phenomenological factors, instructional and teacher factors, demographic factors, and learning history. These are discussed below.

Phenomenological factors - These include 'relevance of instruction and perceived control.' Students are more likely to be engaged when the content they are learning is relevant to them and has relatable applications in the real world.

Instructional and teacher factors - Engagement may also be impacted by the method of teaching. Students are said to be more engaged in 'student-controlled' learning initiatives when compared to 'teacher-controlled' activities.

Demographic factors and learning history - Various demographic factors may affect engagement, such as age and gender, with one gender showing more engagement than another or one age group being more engaged when compared to other age groups.

Also, ‘the degree to which on-task behavior has been rewarded or praised in the past’ has also been shown to affect engagement positively.

Additionally, ‘Issuing appropriate challenges and providing opportunities to enhance skills (e.g., providing immediate feedback and incrementally teaching more complex skills that build upon previously learned skills) may be one of the ideal ways of engaging students’ (Shernoff et al., 2003 p. 160).

The balance between challenge and skill is very meticulous when it comes to achieving the flow state (Csikszentmihalyi, 1998; Shernoff et al., 2003; Csikszentmihalyi,1975), but when achieved can result in student engagement. Despite this, achieving flow in the classroom is not always easy, even if there is a balance between a student’s skill level and the challenge at hand, in such a way to facilitate flow, other elements that are conducive to flow may be lacking, for instance, autonomy, classroom environments are not always autonomous (Biasutti, 2011).

2.6.7 Interrelation Between Flow and SDT

Self-determination theory and flow share several parallels. They are both linked to intrinsic motivation (Wang & Demerin, 2023; Lüking et al., 2023; Kowal & Fortier, 1999), self-determined extrinsic motivation (Kowal & Fortier, 1999), and optimal psychological states (Wang & Demerin, 2023; Lüking et al., 2023). Individuals are more likely to experience flow when they are intrinsically motivated (Wang & Demerin, 2023). Intrinsic motivation is also an element of SDT. When there is satisfaction of the basic psychological needs of autonomy, competence, and relatedness, an individual is more likely to experience intrinsic motivation and, hence, flow (Lüking et al., 2023). Self-determined extrinsic motivation is also positively linked to flow; on the other hand, amotivation has a negative relationship with achieving the flow state (Kowal & Fortier, 1999). SDT and flow both relate to optimal psychological states. When the basic psychological needs of autonomy, competence, and relatedness are met, an individual can have psychological growth and an optimal experience (Wang & Demerin, 2023); flow also relates to an individual achieving an optimal psychological state (Wang & Demerin, 2023; Lüking et al., 2023).

2.6.8 Flow, SDT, and student well-being

Student well-being is a matter of growing concern (Jones et al., 2021; Makaremi et al., 2024), particularly in light of increased levels of mental health conditions coupled with the low rates of student well-being in higher education (Walker, 2022). Considering that there have been many reports of low levels of student well-being (Walker, 2022), sometimes a university-wide approach is taken to facilitate overall well-being (Jones et al., 2021). Conventionally, there are two main interpretations of well-being: hedonic and eudaimonic.

> *"Hedonic wellbeing focuses on pleasure and happiness, and more immediate gratification, while eudaimonic wellbeing emphasizes personal growth, meaning, and self-actualization, contributing to a deeper sense of fulfillment and purpose in life. Both perspectives are essential in achieving a comprehensive and enriched experience of wellbeing."* (Makaremi et al., 2024, p. 2)

However, in recent times, well-being scholars have proposed a more comprehensive definition that comprises both hedonic and eudaimonic components (Makaremi et al., 2024).

Flow promotes well-being and fulfilment. Individuals who experience flow regularly benefit from an increase in concentration, self-esteem, and performance. The effects of flow can facilitate emotional well-being and happiness (Ben C, n.d.). Self-determination theory is also linked to well-being. Support of the basic psychological needs of autonomy, competence, and relatedness fosters student wellness (Lataster et al., 2022; Ryan & Deci, 2020). More specifically, SDT, support for basic psychological needs, can facilitate students' intrinsic motivation and autonomous extrinsic motivation, enhancing their psychological well-being (Ryan & Deci, 2000; Ryan & Deci, 2020).

Well-being should be at the cornerstone of life in higher education, emphasised by ongoing transformation and adjustment to research and feedback (Walker, 2022). Anastasiadis et al., 2018) suggest that a GBL environment can promote student well-being:

"Digital game-based learning approach and serious games in general can be utilized as an educational tool which can boost students' wellbeing and self-esteem, help them improve their soft skills, develop their critical thinking, decision-making and problem-solving skills, as well as maintain a healthy mental and psychological balance." (p. 142).

This further makes the case for GBL as a rounded pedagogical approach with multiple positive benefits that may be applied to classrooms worldwide.

2.7 Game Elements

'Game elements are the design elements used in hedonic games (Beck et al., 2019, p.34). There are many game elements associated with game-based learning. In a review of game elements used in designing game-based learning STEM applications conducted by Juhari et al. (2020), the most common elements found in the reviewed studies (from 2014 to 2018) were challenge, time pressure, rewards, leaderboard, feedback, scaffold, badges, and score. Juhari & Abu Bakar (2020) also reported that in a systematic review of 137 papers on GBL, the most common game elements used in GBL studies were collaboration, role-playing, exploration, narrative, complexity, competition, and strategy.

The above game elements have their respective strengths and weaknesses, and these should be considered during the design stage of the research. Individual game elements are discussed below in this section. In my personal view of game elements, I prefer a competitive and challenging game environment, which I find more enjoyable. I also like feedback and leaderboard, as this gives me an idea of my performance and allows me to make adjustments if necessary. I also enjoy achieving rewards.

There are many features associated with games and GBL that fall under the umbrella of game elements, and continued research investigating their impact in different contexts is imperative.

There are several known benefits of adding game elements to teaching and learning. Studies have reported that GBL positively impacts motivation, engagement, and overall student satisfaction (Herout, 2016). Careful selection and inclusion of game elements in education design are recommended to realise improvements in learning outcomes, bearing in mind that different game elements result in different learning outcomes (Juhari & Abu Bakar, 2020; Shabihi et al., 2016). It is also consequential to harmonize educational theories and game design to accomplish optimal educational games (Elsattar, 2018). 'To have well-designed learning games which are able to motivate learners and promote their knowledge acquisition using both game-elements and pedagogical principles is required' (Shabihi et al., 2016, p. 612).

Additionally, the effect of the game element on learning outcomes may vary based on the learner's personality type. An individual's personality may influence their preference of game-element in GBL. For example, when introverts were compared with extroverts, it was found that introverts preferred points, badges, and clear goals, and extroverts preferred progress tracking and leaderboards. Personalisation of game elements that align with the learner's personality type may improve learning outcomes (Shabihi et al., 2016), even though this may not be easy to achieve in a classroom setting due to time constraints and the meticulous adjustments that may be required. Using several game elements simultaneously may somewhat mitigate this.

In my own experience during the GBL intervention, the learners overwhelmingly preferred the competitive game element, but in another classroom, somewhere else, this may not be the case. Also, among the same group of students, many of them liked the time pressure element while others did not. I am not sure what the difference in preference is based on in this instance.

The study in which Shabihi et al. (2016) made the claims above reported a small sample size, and although this raises questions about the precision and reliability of the results, it is certainly a good area to position an inquiry into the impact of GBL in the classroom as the findings may benefit classroom outcomes.

Many researchers combine game elements during interventions. This practice of combining game elements is very typical in game-based research. For example, Ortiz et al. (2022), in their review of 30 studies, found that 60% of the studies used a combination of elements. However, Ortiz et al. (2016) state that this makes it difficult to assess what exactly was responsible for the positive or negative outcome.

In the context of research, testing multiple elements simultaneously may compromise the findings in that students may mix their feelings towards the elements and give overall scores. The researcher may not truly know the impact of an individual element. To mitigate this, the researcher could ensure at the design stages that the students have the opportunity to respond to questions about each element and or respond to open-ended questions/focus groups (for example) that can capture the essence of their perception. I can understand why a researcher may want to mix elements; duration and financial constraints may discourage a researcher from investigating one element at a time. Finally, an incentivizing classroom is a fun and dynamic undertaking and limiting an intervention of this nature to one element may be a missed opportunity since elements can be successfully explored with careful consideration and planning. On the other hand, evaluating one game element at a time may allow an in-depth inquiry into that element, allowing the researcher to explore many aspects of that element.

'Adding game-design elements to the classroom allows for differentiated instruction and adds the potential for rewards as well as significant challenges for learning and teaching.' (Wiggins, 2016, pp. 5-6).

The incentivizing nature of game elements addition to learning has the potential to engender beneficial outcomes such as motivation (Juhari & Abu Bakar, 2020; Elsattar, 2018; Lee et al., 2023), engagement (Juhari & Abu Bakar, 2020; Elsattar, 2018; Shabihi et al., 2016; Lee et al., 2023) enhanced learning performance (Juhari & Abu Bakar, 2020; Shabihi et al., 2016, 2016; Lee et al., 2023) and enjoyment (Juhari & Abu Bakar; Chen et al., 2022). In addition to this, the transformed classroom environment may be enticing to students as they get to experience learning away from the traditional 'chalk and talk.' On the other hand, there are challenges, such as possibly sending the wrong message to students, i.e., they should only learn when rewarded (Wiggins, 2016) or the use of too many game elements resulting in overstimulation of the players (Greipl et al., 2020). However, considering all the benefits outweigh the challenges.

In the next few sections, I will discuss some of the most common game elements and explore some of their impacts on classroom learning.

2.7.1 Competition

Competition is a key design element in gameplay, irrespective of whether the game is for edutainment or entertainment. Competition and its potential are not new or unfamiliar concepts, so it is not surprising that game creators ensure that their games include various competitive elements.

Competition can have various benefits. For example, comparing students' achievements can act as a form of motivation if the class is allowed to see the scores and the winners, empower students by making them more aware of their skills and competencies (Silva et al., 2019), advancing in competence (Greipl et al., 2020), engage players, encouraging social interaction and promoting sustained gameplay (Qian & Clark, 2016).

Healthy competition can engender positive outcomes (Silva et al., 2019), but some researchers report negative effects of competition; for example, Greipl et al. (2020) stated that competition negatively impacted collaborative learning for students with low ability and it was reported in another study that students in a gamified course performed worse than their non-gamified counterparts in their final exam. Giving rewards that encouraged competition via a leaderboard was claimed to have a negative impact on student motivation. Hanus & Fox (2015) reported this finding after their gamified classroom intervention: 'The results suggest that at best, our combination of leaderboards, badges, and competition mechanics do not improve educational outcomes and at worst can harm motivation, satisfaction, and empowerment' (p. 159).

2.7.2 Challenges

Challenge is one of the most common game elements in GBL design (Juhari & Abu Bakar). It fosters competitive collaboration (Juhari & Abu Bakar, 2020), provide learners with a sense of accomplishment (Juhari & Abu Bakar, 2020; Qian & Clark, 2016), and enhances the impact of engagement on academic performance when combined with other game elements (Camacho-Sánchez et al., 2022).

The pedagogical relevance of challenges is to structure and systemise the students' attempts in a meaningful way, according to Silva et al. (2019).

On the other hand, one downside of the challenge game element is that the level of challenge may not match the learners' competence level, and this may result in reduced engagement and knowledge acquisition due to frustration (Juhari & Abu Bakar, 2020). A good balance of challenge level and player's skill level is required to maintain flow (Qian & Clark, 2016; Elsattar, 2018).

2.7.3 Leaderboard

Some game elements are interrelated; for example, leaderboards encourage competition and challenge players. Leaderboards refer to ranking players according to their scores or level of activity in the game. Leaderboards enable players to see and compare their progress with other players, thereby fostering challenge and competition (Shabihi et al., 2016).

There are other benefits of leaderboards as a game element. Leaderboard can motivate learners (Juhari & Abu Bakar, 2020; Lee et al., 2023; Beck et al., 2019; Camacho-Sánchez et al., 2022), encourage engagement (Lee et al., 2023; Shabihi et al., 2016; Camacho-Sánchez et al., 2022), promote self-improvement (Shabihi et al., 2016), relatedness within a group Silva et al., 2019), competition as well as enable students to monitor their progress (Silva et al., 2019).

Leaderboards may also have a negative impact on some learners, according to Lee et al. (2023), who reported that high-achieving students are motivated by moving up on leaderboards, while low-achievers may need more intrinsic motivational tools.

2.7.4 Feedback

'Feedback is the information given to players whether formatively or summatively based on the players' action.' (Yunus & Zaibon, 2021, p. 53). It is also a very common game element used in game-based learning (Juhari & Abu Bakar, 2020) and is seen as one of the most essential elements (Silva et al., 2019). Feedback informs players of their progress in the game (Shabihi et al., 2016), giving them a feeling of uninterrupted progression and hence keeping them engaged in the learning process (Zabala-Vargas et al., 2021). In addition to engagement, feedback also entertains and motivates players (Silva et al., 2019).

The frequency, intensity, and speed of the feedback are crucial for the maintenance of engagement during the learning process. When feedback is effectual and immediate, participants are more successfully engaged, in particular, when the focus is on short-term goals and rewards compared to long-term goals (Lee et al., 2023). In a classroom GBL setting, a platform such as Kahoot! provides immediate feedback (not detailed) with a high level of frequency and has been shown to impact learning and engagement.

From a theoretical perspective, immediate feedback is one of the components that is said to encourage the flow state. Flow brings about feelings of focus, involvement, and enjoyment (Elsattar, 2018). Immediate feedback also aligns with the SDT, in that it fulfils the need for competence, as it gives learners a quick assessment of their performance, allowing them to take control and make necessary adjustments, making them feel more autonomous (Lee et al., 2023). From my experience, students can also foster a feeling of relatedness during their in-between discussions after feedback.

2.7.5 Time Pressure

Juhari and Abu Bakar (2020) looked at popular game elements used in designing game-based learning STEM applications for the period 2015-2019 and found that time pressure was among the most common game elements in these applications.

The time pressure element requires speed and focus (Juhari & Abu Bakar, 2020), as students may be required to solve a problem in a required time. In some instances, the students may even be rewarded for completing the task before other competitors; that is, they get more points if they get the correct answer in a shorter time.

The time pressure element is a feature in Kahoot! games (Wang & Tahir, 2020; Cadet, 2023; Wahyuni & Etfita, 2023; Lofti et al., 2021; Sianturi & Hung, 2022; Mdlalose et al., 2021; Lopez & Tucker, 2024; Alawadhi & Abu-Ayyash, 2021) and while many learners have a positive perception of the use of Kahoot! (Wang & Tahir, 2020; Cadet, 2023; Mdlalose et al., 2021), some find the time pressure element challenging (Wang & Tahir, 2020; Cadet, 2023; Wahyuni & Etfita, 2023; Mdlalose et al., 2021).

It was reported that time pressure affected 'focus and attention' (Lofti et al., 2021), caused distraction (Sianturi & Hung, 2022), and can create apprehension (Mdlalose et al., 2021) and frustration (Lopez & Tucker, 2024) for some students. On the other hand, some students appreciated the time pressure element and its impact on their sustained engagement (Alawadhi & Abu-Ayyash, 2021).

2.8 Benefits of GBL in Higher Education Mathematics

Researchers have reported many benefits of game-based learning in the mathematics classroom. These benefits may be classified in the psychological domains of cognitive, social, motivational, and emotional. Some of these benefits include, increased student motivation (Nurul Hasana, 2018; Gil-Doménech & Berbegal-Mirabent, 2019; Koparan, 2019; Shaker et al., 2021; Rosillo & Montes, 2021; Zabala-Vargas et al., 2021; Karakuş & Baki, 2020; López et al., 2017; Pedersen et al., 2012), improvement in student collaboration (Nurul Hasana, 2018; Gil-Doménech & Berbegal-Mirabent, 2019; Suparlan et al., 2019; Ting et al., 2019; Kaedah et al., 2020; Rosillo & Montes, 2021; Karakuş & Baki, 2020; Pedersen et al., 2012), improvement in learning (Abdu et al., 2015; Gil-Doménech & Berbegal-Mirabent, 2019; De Troyer et al., 2019; Suparlan et al., 2019; Ting et al., 2019; Koparan, 2019; Marie et al., 2020; Delgado-Gómez et al., 2020; Shaker et al., 2021).; Agbonifo et al., 2021; Wang et al., 2021; Koparan, 2022; Rosillo & Montes, 2021; Lopes et al., 2017), better student satisfaction (Bortot & Coles, 2019; Gil-Doménech & Berbegal-Mirabent, 2019; Delgado-Gómez et al., 2020; Zabala-Vargas et al., 2021; Perera et al., 2017), enhanced student engagement (Nurul Hasana, 2018; Shaker et al., 2021.; Heller & Pogaru, 2021; Rosillo & Montes, 2021; López et al., 2017; Pedersen et al., 2012) and a scaffolding tool (Abdu et al., 2015; Delgado-Gómez et al., 2020; Kaedah et al., 2020; Agbonifo et al., 2021).

2.9 Challenges of Game-based Learning in Higher Education Mathematics

Although there are many benefits associated with game-based learning, there are also reported challenges, although the benefits appear to outweigh the challenges.

Many researchers advocate game-based learning as auspicious. However, other researchers report on the challenges, such as the distraction that comes along with gameplay (Herout, 2016) and the negative potential of instant feedback without reflection (Gill, 2018).

As it relates to GBL in mathematics some challenges reported by researchers included the scoring method for games needs improvement (Gil-Doménech & Berbegal-Mirabent, 2019), intervention was found inadequate to facilitate the intended outcome (Marie et al., 2020), Learner Management Systems (LMS) or school cannot adequately facilitate intervention (Delgado-Gómez et al., 2020; Wang et al., 2021), students had decreased interest in game elements over time (Perera et al., 2017), students experience ‘help seeking’ anxiety (Shaker et al., 2021).

The overall benefits of GBL implementation in higher education mathematics classrooms appear to be far greater than the challenges researchers reported. There is a vast amount of literature on the benefits of adding game elements interventions to teaching and learning. Kennedy & Lee (2018), in their review of 22 articles on GBL and gamification in Asia, found the following: ‘With regard to the impact of games on learning outcomes, 13 articles reported all positive findings, while nine articles reported partially positive findings. No single article reported only negative findings’ (Kennedy & Lee, 2018, p. 13). This finding is consistent with the findings of this review, where most of the papers reported a positive outcome, and a few reported both positive and negative.

When it comes to the limitations faced during HE mathematics GBL interventions and research, these are some that were reported by the studies reviewed, small sample size (Shaker et al., 2021; Delgado-Gómez et al., 2020; Heller & Pogaru, 2021), low survey response rate (Shaker et al., 2021; Perera et al., 2017), technical limitations (Wang et al., 2021), survey tool limitations (Gil-Doménech & Berbegal-Mirabent, 2019), sampling bias (Shaker et al., 2021; Karakuş & Baki, 2020), limited duration with the game intervention (Foss et al., 2014), poor scoring method that lacked equity and fairness (Gil-Doménech & Berbegal-Mirabent, 2019), students insufficient subject knowledge of mathematics content used in games (Bortot & Coles, 2019), implementation limitations (Delgado-Gómez et al., 2020), lack of expertise (Wang et al., 2021; Perera et al., 2017). Time constraints (Karakuş & Baki, 2020; Perera et al., 2017), lack of control group (Perera et al., 2017), exploratory research design limitation (Holden, 2016; Meletiou-Mavrotheris & Prodromou, 2016), low questionnaire feedback (Foss et al., 2014) and game application limitations (Wang et al., 2021)

To get the best from game-based learning, the criticisms must be considered and mitigated where possible so that the benefits to students are optimal. Furthermore, reported limitations should be factored into the research at the planning stage to avoid factors that may impact the intervention negatively.

2.10 Research Gaps

A review of the existing literature on GBL in higher education mathematics has revealed that multiple positive implications may be derived when GBL is implemented in a classroom setting, including positive academic outcomes, improved motivation, and engagement.

However, some research gaps have also been identified. This section aims to highlight these gaps and demonstrate how my research can contribute to the current shortfall while contributing to the wider academic discourse on GBL in mathematics education.

The literature review uncovered a lack of engagement with theory when researchers investigated mathematics game-based learning at the higher education level. Theoretical engagement is important as it can provide a good grounding and guiding framework for conducting your research. Investigating key elements of a theoretical framework can shed light on those elements and inform practice, theory, and future research. This research is grounded in SDT and flow theory and aims to contribute to the theoretical discourse of game-based learning under these lenses.

Another gap identified is a lack of research on game-based learning as a whole in the Caribbean region. There is very little research on GBL in the Caribbean. My study can contribute to the literature in this area in the Caribbean context since the study was done at an institution in the Caribbean.

A third research gap identified is a lack of GBL studies in mathematics at the Higher education level. Most research on GBL in mathematics was conducted at the primary and secondary levels. This research has been conducted at the higher education level and is poised to add to the knowledge base of HE game-based learning.

Finally, there appears to be a lack of mathematics and chemistry interdisciplinary game-based learning studies. The initial systematic review conducted did not reveal any instances of mathematics GBL in a chemistry context. Mathematics is an integral part of chemistry, and proficiency in mathematics has been linked to success in chemistry, as stated above (Spencer, 1996; Willis et al., 2022; Powell et al., 2020; Williamson et al., 2020). Therefore, researching the impact of mathematics GBL in the chemistry classroom could provide valuable insight into students' learning outcomes and experiences.

Addressing these research shortfalls is pivotal for extending the knowledge base in the field of game-based learning. This research aims to fill these gaps by investigating mathematics GBL, grounded in the flow and SDT theory, at the higher education level in a Caribbean higher-education institution. A convergent mixed-method study has been conducted in a chemistry classroom, exploring the following research questions:

i. To what extent does mathematics game-based learning (GBL) impact students' academic performance?
ii. What are students' perceived competence, relatedness, and autonomy when game-based learning is used in their classroom?
iii. What are students' learning experiences of flow?
iv. What are students' perceptions of the benefits and challenges of mathematics GBL in their course?

My contribution that results from conducting this research will shed light on the identified gaps, contribute to the academic discourse and provide practical implications for academic stakeholders.

2.11 Conclusion

Although GBL has both positive and negative impacts, its advantages are overwhelmingly common. They can be incorporated into classroom pedagogies to facilitate more active learning that is more entertaining and attractive to students, facilitating learning in a non-traditional way or at least supplementing existing methods. Incorporating game elements into mathematics classrooms is noteworthy. It should be seriously considered so that mathematics learning environments can benefit from proven research and move away from outdated and mundane ways of facilitating education. As shown from the literature review, students can benefit from improvement in engagement and motivation, collaboration and student-centred learning, mathematics scaffolding, and student satisfaction and enjoyment through pedagogues and stakeholders, including game elements in the classroom, whether physical or virtual.

3 Methodology

3.1 Introduction

The methodology chapter, in many respects, is the crux of a research study. It functions as a research map illustrating the direction the study will take, the methods it will employ, why they are appropriate methods, and how these methods will lead to findings that are substantiable and statistically reliable.

This study uses a convergent mixed methods approach. The philosophical worldview underpinning the study is pragmatism. A mixed methods approach was chosen as it was seen as the most suitable to answer the following research questions:

i) To what extent does mathematics game-based learning (GBL) impact students' academic performance?
ii) What are students' perceived competence, relatedness, and autonomy when game-based learning is used in their classroom?
iii) What are students' learning experiences of flow?
iv) What are students' perceptions of the benefits and challenges of mathematics GBL in their course?

3.2 Research Approach

This section looks at the different research approaches while highlighting and justifying the ones chosen for this study. 'Research approaches are plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation.' (Creswell, 2018, p.40). Creswell (2018) further elaborates that a research plan incorporates many decisions. The basis of these decisions should include elements such as the researcher's philosophical assumptions, the research design, and the research methods. Figure 3.1 shows the interconnection between these three elements from the perspective of this research.

In this research, I assumed a pragmatism philosophy, acknowledging the research questions and the quest to answer them as a focal point. I chose to explore my research questions using a mixed methods approach as I felt this method would facilitate the best answer to the research questions while ensuring a robust overview of the research intervention. The research methods consist of exploring the research questions via several data collection instruments, then analysing them using quantitative and qualitative techniques, and interpreting the findings while showing reliability and validity.

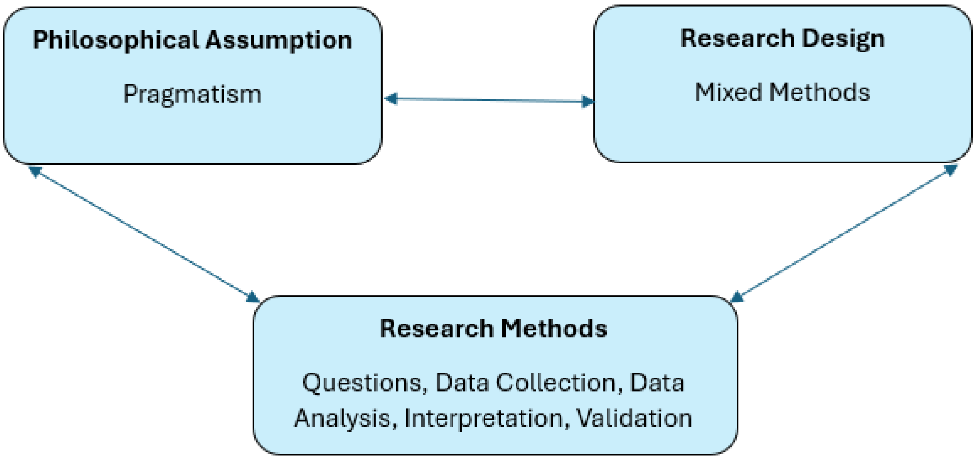

Figure 3. 1 Research framework (Adopted from Creswell, 2018, p.43)

Additionally, Creswell (2018) states that when choosing a research approach, the researcher should consider the 'nature of the research problem or issue being addressed, the researchers' personal experiences, and the audiences for the study.' (Creswell, 2018, p.40). In the case of this study, the research problem has existed for a while, and interventions that seek to understand the issue more and/or find a solution are of utmost importance. I have almost two decades of experience in higher education in the capacity of a mathematics lecturer and this complements my suitability to conduct research of this nature with the student participants and wider higher education audience.

There are three main research approaches, otherwise called research methodologies. These are qualitative, quantitative, and mixed methods research. Creswell (2018) describes qualitative research as 'an approach for exploring and understanding the meaning individuals or groups ascribe to social or human problem,' quantitative research as 'an approach for testing objective theories by examining the relationship among variables', and mixed methods research as 'an approach to inquiry involving collecting both qualitative and quantitative data, integrating the two forms of data, and using distinct designs that may involve philosophical assumptions and theoretical framework' (Creswell, 2018, p.41).

The research approach chosen for this study is a mixed methods approach. The reason for combining both quantitative and qualitative methods was to gain a better understanding of the views and experiences of the participants within the context of the game-based study intervention. As stated in Creswell (2018), 'the core assumption of this form of inquiry is that the integration of qualitative and quantitative data yields additional insight beyond the information provided by either the quantitative or qualitative data alone.' (Creswell, 2018, p.41-42).

As stated in the problem statement, most of the students who take the secondary mathematics exit examination, the Caribbean Secondary Education Certificate (CSEC), are underperforming. In May/June of 2022 (the last available data from the CSEC examination council), 66,347 students took the mathematics CSEC examination throughout the Caribbean. There was an overall pass rate of 37%, with the mean score of the students being 38.1%, which is 76.22 out of a possible 200 marks. Students' overall scores for the three assessed profiles are as follows: knowledge profile (42.19%), comprehension profile (35.73%), and reasoning profile (31.86%) (Caribbean Examinations Council, 2022). This suggests that students are not demonstrating a satisfactory level of competence in these mathematics exams. Students below par performance in basic mathematics from secondary school affects their performance when they transition to tertiary-level education and take mathematics or any course with a mathematics component.

In some institutions in the Caribbean, particularly those that follow the 'American model,' all students take mathematics as part of their general education requirement irrespective of whether they are majoring in Mathematics or not. They need to pass these mathematics courses to progress through their respective degree programme.

Pedagogical methods that enhance engagement, motivation, and learning could help these students improve their mathematical competencies and hence their progress.

Due to the positive feedback associated with GBL (Suparlan et al., 2019; Zabala-Vargas et al., 2021) coupled with my experience as a university mathematics lecturer for almost fifteen years and seeing the response students have when I use games in the classroom, I decided to investigate students' learning and attitude towards learning using a GBL intervention. A mixed methods approach was chosen because I was interested in seeing whether the game-based intervention had an impact on students' grades, but I was also interested in hearing the students' voices within two theoretical frameworks, self-determination theory (SDT) (Jalil et al., 2020; Chan et al., 2019; Tobon et al., 2020; Zainuddin et al., 2018) and flow theory (Almeida & Buzady, 2019; Catal´an et al., 2019; Bitri´an et al., 2020).

3.2.1 Mixed Methods Approach

The predominant research approaches, quantitative and qualitative, have a history of 'war' beginning in the seventies and spanning more than two decades. Researchers argued on the side of their chosen approach claiming paradigmatic superiority, with each side agreeing that both approaches cannot be combined. It was not until the nineties that researchers started mixing methods. The progression of the mixed methods approaches consistently gained traction from then to the present day. Published mixed methods studies span several disciplines, including business research, psychology, sociology, education research, and health service research (Maarouf, 2019).

Objectivism and positivism form the core of quantitative research. This research approach is deductive and focuses on examining the relationship among variables. On the other hand, subjectivism and interpretivism are the basis of the qualitative research approach, which is exploratory in nature and follows an inductive pathway (Maarouf, 2019).

The mixed methods approach involves the researcher mixing both quantitative and qualitative methods. Creswell (2018) describes the mixed method approach as being on a continuum, residing somewhere between qualitative and quantitative approaches.

This research used a mixture of quantitative and qualitative data collection methods. A questionnaire (see Appendix A) was used to collect quantitative (Likert-type questions) and qualitative data (open-ended questions), focus groups (see Appendix B) to collect qualitative data, students' grades during the intervention to collect quantitative data as well as the grades of students of past cohorts to collect quantitative data. The convergent mixed methods (Creswell, 2018) approach was used, where both quantitative and qualitative data were collected at approximately the same time.

3.2.2 Research Philosophy

There are several philosophical positions or assumptions that a researcher can take when they decide to embark on research. These research assumptions are referred to as 'philosophical worldviews' by Creswell (2018. p.44). In other literature, these research assumptions are called research paradigms, epistemologies, and ontologies or simply research methodologies (Creswell, 2018). Some of the predominant worldviews are post-positivism, constructivism, transformative, and pragmatism (see Table 3.1).

Postpositivism	**Constructivism**
• Determination • Reductionism • Empirical observation and measurement • Theory verification	• Understanding • Multiple participant meanings • Social and historical construction • Theory generation
Transformative	**Pragmatism**
• Political • Power and justice-oriented • Collaborative • Change-oriented	• Consequences of actions • Problem-centered • Pluralistic • Real-world practice-oriented

Table 3. 1 Four common research philosophies (Adopted from Creswell 2018, p.45)

This study adopts a pragmatism philosophy. In this philosophical perspective, 'researchers emphasize the research problem and question and use all approaches available to understand the problem' (Creswell, 2018, p.48). Pragmatism, as a philosophical foundation for mixed methods research, uses 'pluralistic approaches' to enhance understanding of the research problem (Creswell, 2018). In this study, both quantitative and qualitative techniques were employed as this was seen as the best approach to addressing the research problem and answering the research questions. A triangulation of research methods was employed to gather the information needed to answer the research questions.

3.2.2.1 Pragmatism

Pragmatists aim to determine 'what works' and what is likely to bring a solution to existing research questions or problems (Creswell, 2018). A researcher employing the pragmatic approach uses a form of abductive reasoning, resulting in the researcher moving back and forth between induction and deduction. This is traditionally done by 'converting observations into theories and then assessing these theories through action' (Morgan, 2007, p.71).

In the case of this research, there is a slight variation to the traditional abductive approach whereby the SDT and flow theories were used to investigate game-based learning via active in-class game-based pedagogy.

Scholars use various philosophies to validate the mixed methods approach (for example, Maxwell & Mittapalli, 2010; Fetters & Molina-Azorin, 2017b). Many consider pragmatism to provide a suitable philosophical rationale for mixed methods studies (Feilzer, 2010; Parvaiz et al., 2016). Maarouf (2019) explores pragmatism from an ontological as well as an epistemological stance. From an ontological perspective:

> *The reality cycle is the ontological stance that is based on the existence of one reality in a certain context at a certain point of time and multiple perceptions of this reality in the social actors' minds. Social actors' perceptions of reality control their behaviours which causes changes in the context and in*

consequence in reality. As reality changes, the pragmatic researcher can switch between the two positions of the one reality or the multiple perceptions of this reality (Marouf, 2019, p.10).

From an epistemological perspective:

The epistemological stance, the double-faced knowledge, suggests that quantitative and qualitative researchers' claim they can only accept either the observable or the unobservable knowledge is just a difference in their points of view not a difference in the nature of knowledge itself. Thus, any type of knowledge can be seen as observable or unobservable based on the instantaneous ontological position of the pragmatic researcher (Marouf, 2019, p.10).

3.2.3 Research Design

The research design used in this study is convergent mixed methods (see Figure 3.2). Both quantitative and qualitative data were collected around the same time and then later combined and interpreted (Creswell, 2018). A mixed methods design was chosen because I wanted to see if the game-based intervention had an impact on the students' academic performance, as well as investigate their learning experience within the intervention based on the theoretical framework. I was also interested in the participants' perception of the benefits and challenges of game-based learning in the classroom.

Students completed a pretest at the beginning of the game-based intervention and then a posttest at the end of the intervention. The results of the pretest and posttest provided quantitative data relating to the students' performance before and after the research intervention. Students also completed a questionnaire at the end of the intervention. The questionnaire collected both qualitative and quantitative data. In addition, a focus group providing further qualitative data was conducted. Finally, quantitative data was also collected from the final grades of the participants and compared with secondary data from the final grades of previous cohorts of students who took the same courses that were investigated.

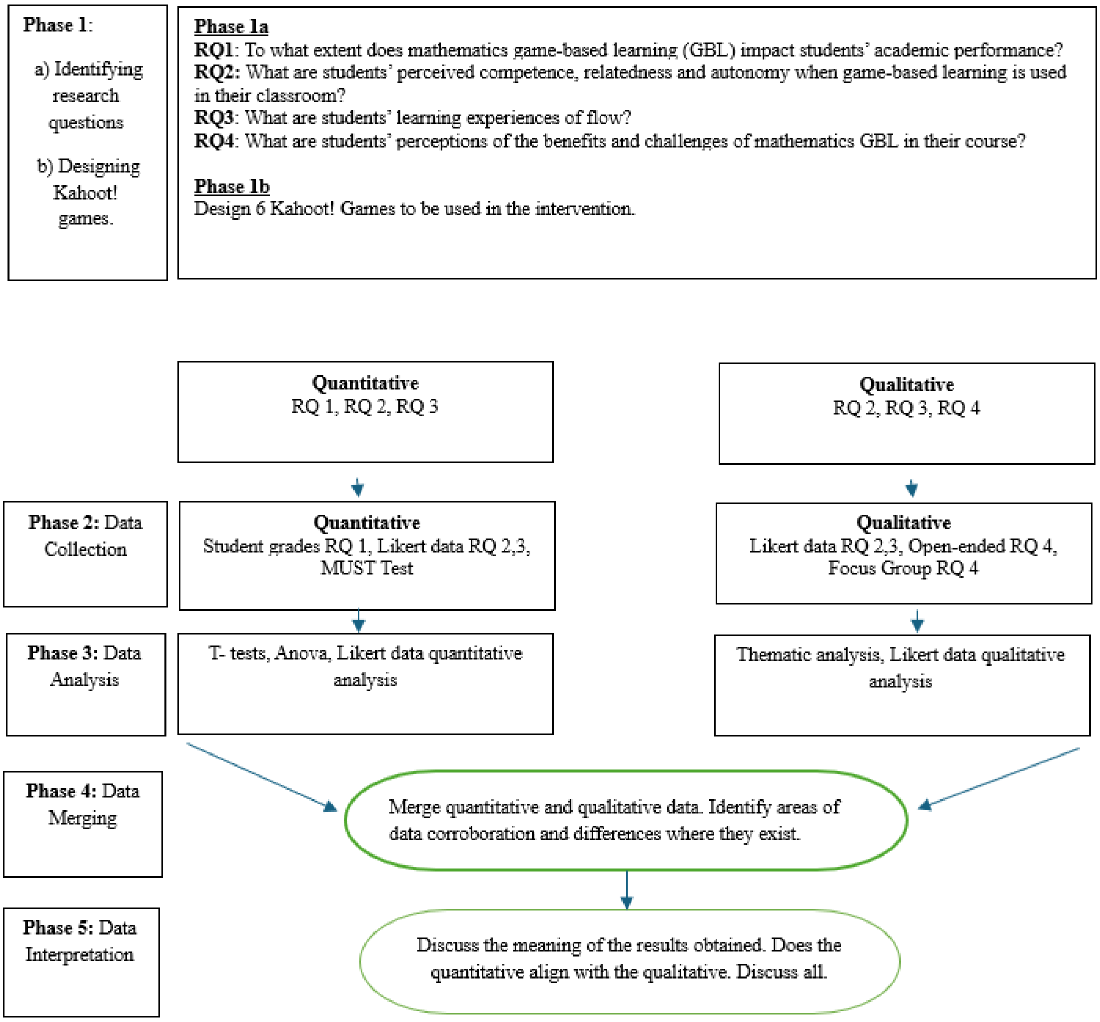

Figure 3. 2 Research Design

3.2.3.1 SDT and Flow in the Research Phases

The theoretical frameworks of SDT and flow were considered consistently across all research phases, including identifying the research question, designing the games, collecting, analysing and interpreting the data. By integrating both SDT and flow at various stages, this ensured a theoretically grounded approach. Below, I provide a more detailed explanation of how SDT and flow were applied across each phase of the research.

Phase 1a – Identifying Research Questions

The formulation of the research questions was informed by a critical examination of the research problem and the need to generate meaningful answers. Since the research was centred around improving mathematics outcomes in a fun and motivating way for students, the decision was to include specific research questions that focused on competence and student experience while allowing students to give their perspective on the benefits and challenges of the process.

In this phase, the research questions captured the essence of the theoretical frameworks. More precisely, RQ 1 measured the students' academic performance. Competence is an element of SDT. RQ 2 delved more into SDT, looking at competence and the other elements of SDT, autonomy and relatedness. RQ 3 explored the flow experience, and RQ 4 invited students to share their perceptions of the benefits and challenges of their experience, potentially illuminating elements that have negative and positive impacts on the theoretical frameworks and their overall experience.

Phase 1b- Designing Kahoot! Games

Six Kahoot! games were designed to be used in the game-based intervention. The students had a test run with one of the games to ensure their familiarity with the platform before the start of the intervention. This was purposefully done to help bring students at ease during the intervention. Another consideration taken at this stage was that the games were five or six questions long. The aim was to maintain engagement while minimising the risk of student frustration.

Phase 2- Data Collection

The instruments chosen for data collection were well-suited to provide insights into the theoretical framework of SDT and flow. The MUST test (administered as a pretest and posttest), the students' final grades, and the grades of previous cohorts were used to give information regarding students' competence. Did students learn during the intervention? These grades provided information to answer that question. Competence is an element of SDT, so this data provided information for that element of the SDT.

The Likert instruments measured SDT and flow on a 5-point agreement scale. Responses to the Likert questions gave an idea of students' average level of agreement and indicated the direction of the agreement. The Likert responses also provided insights into the variability of the data collected. This provided valuable information about the students' perception of their experience of SDT and flow.

Open-ended questions and focus groups were used to get additional information. The students got to have a voice outside of the constraints of a Likert-type instrument. Students could add valuable information relating to their experience of SDT and flow. The students' explicit input helped to identify what went well and what did not. It allowed the students to reflect on the process and offer valuable insights that may be used in future SDT and flow inquiries.

Phase 3- Data Analysis

Several methods were used for data analysis. The chosen methods helped to provide information to shed light on SDT and flow in the game-based research. T-tests and ANOVA were used to compare and analyse the difference in students' pretest and posttest results, as well as students' grades. This gave information regarding students' competence, whether there was an increase in competence, and whether it could be attributed to the intervention.

Likert question data, when analysed, provided insight into the students' experience through the lens of the theoretical frameworks, as mentioned above in Phase 2.

Thematic analysis (Braun & Clarke, 2021) helped to dissect the open-ended and focus group data, providing crucial information regarding alignment with the theoretical framework and overall student experience.

Phase 4 – Data Merging

In this phase, data were examined, and commonalities were identified. The theoretical framework provided structure and guided the process of data merging. For example, results from the t-test and ANOVA were compared to Likert and open-ended responses and focus group results. Was there a common outcome? The qualitative and quantitative data obtained highlighted the interrelationship between SDT and flow.

Phase 5 – Data Interpretation

The data was interpreted through the lens of the SDT and flow. This allowed me to make meaning from the data obtained from the intervention. What was the data saying? How did the game-based intervention in my context look through the lens of SDT and flow? In this phase, I drew conclusions and created discussions based on my interpretation of the data from the two theoretical lenses.

3.3 Participants

The participants comprise students from three Chemistry classes: two sections of General Chemistry I and one section of General Chemistry II. There was a total of 43 participants among the groups. All three groups had the same teacher. The participants were informed about the study by their class teacher. At that point, the participants were also informed that the study intervention would form part of the teaching pedagogy, which was compulsory, but the decision to participate in the questionnaire and focus group and have their grades from the pretest and posttest used in the study was voluntary. They were assured that their participation would not result in any reward or their nonparticipation in any penalty.

3.4 Sampling Method

The sampling method used in the study is purposive sampling. Purposive sampling is a non-probability sampling technique. Taherdoost (2016) describes purposive sampling as 'a strategy in which particular settings persons or events are selected deliberately in order to provide important information that cannot be obtained from other choices' (Taherdoost, 2016, p.23). In the case of this research, the groups of chemistry students chosen for the study were seen as ideal candidates for the research given that there was an apparent mathematical gap in many previous cohorts of students on General Chemistry I and General Chemistry II courses, as reported by the chemistry professors, and this was affecting their performance on the course.

3.5 Research Instruments

The instruments and the techniques used to collect the data are given below. A triangulation of data collection methods was used to gather data for this research. These methods were deemed appropriate to get sufficient data to answer the research questions.

3.5.1 Basic Mathematics Review

After students were informed of the game-based intervention by their class teacher, I was asked to provide the classes with a basic mathematics review session. The class teacher informed me of the topics of interest, and I created a PowerPoint presentation covering basic mathematics topics such as multiplication and division of whole numbers, computations with fractions and decimals, rules of exponents, evaluating algebraic expressions, computations with scientific notations and transposing formulae. There were three classes, and each of them had a PowerPoint session that lasted approximately 45 minutes. The sessions were given at the beginning of the semester and integrated into their regular class session.

3.5.2 Pretest and Posttest

Two different versions of the MUST (Math-up Skills Test) were used for the pretest and posttest. The two different versions had comparable questions with similar levels of difficulty. For example, questions 1 and 2 for both versions of the MUST test are:

Version 1

1. *Multiply:* 87×96
2. *Multiply:* $(3.5 \times 10^{-9})\ (2.0 \times 10^{17})$

Version 2

1. *Multiply:* 78×96
2. *Multiply:* (2.5×10^{-9}) (3.0×10^{17})

The MUST tests are validated instruments that were 'statistically proven to be highly reliable (KR-21 = 0.821) and no statistical differences between versions were shown to exist' (Petros et. al., 2018, p. 5).

Some of the topics included on the MUST tests are multiplication of two-digit numbers, multiplication, and division of exponential notation, transposing formulae, evaluating expressions, converting fractions to decimals, and balancing chemical equations.

Students were asked to print their names on the MUST test paper to make it easier to match pre and posttest after both tests were completed.

A different version of the test was given for the pretest and posttest to ensure that students were not simply memorizing the answers. There were 15 questions on each version of the modified MUST test. The duration of each version was 15 minutes, and students were allowed to use a calculator. They were required to show all working. Each question carried 1 mark, and no penalty was given for incorrect answers.

Both tests were given in a face-to-face setting on printed copies to the students. The pretest was given before the game-based intervention started, and the posttest was given after the intervention was completed. The pretest and posttest were given about 6 weeks apart.

Results from the tests will provide comparable information on student performance before and after the game-based intervention. Additionally, this can provide information on students' progress and potentially illuminate the impact of the game-based intervention on their final course grades. Dimitrov and Rumrill (2003) state that 'the use of pretest scores helps to reduce error variance, thus producing more powerful tests than designs with no pretest data' (p. 160).

After the pre and posttests were completed, they were marked by two different professors, and the grades were compared on an Excel table. For instances where both professors had a different grade for a student, the question was revisited, and both professors re-marked. In the end, both professors had the same grade for each student.

The total number of students who completed the pretest was different from the total that completed the posttest. This resulted in some discarded results.

3.5.3 Kahoot! and Other Games

Kahoot! is a Norwegian web-based learning platform designed for use in various environments, including the home, the workplace, and the classroom. Since its launch in 2012, the Kahoot! platform has had 'hundreds of millions of learning sessions with a billion participants in more than 200 countries and region'. Kahoot! may be used in a face-to-face setting or virtually. Its use in the education sector is far-reaching. Currently 'over 8 million teachers globally, hundreds of millions of students and families' use the Kahoot! platform (https://kahoot.com/company/).

Kahoot! has been used in mathematics game-based research (Setiawan, 2020; Shaker et al., 2021; Prieto et al., 2019) and has been found to motivate students (Gil-Doménech & Berbegal-Mirabent, 2019; Shaker et al., 2021; Rosillo & Montes, 2021) and bring about classroom engagement (Shaker et al., 2021; Heller et al., 2021).

In the classroom context, a user (student) can connect to the Kahoot! platform by going to the website (https://kahoot.it/) or downloading the Kahoot! application to their electronic device. A game pin is generated by the host (teacher) via the platform and shown to the students for them to join the Kahoot! game/quiz. Alternatively, students can scan a generated quick response (QR) code that is on display on the host screen to join the game.

Students then input a nickname or choose an automatically generated one to join the game. Students can see their nickname on the host's screen as well as the nickname of all the other players before the game commences.

Six Kahoot! games were developed to be used in the mathematics game-based intervention. One game was used for the students to practice with their teacher before the intervention started. The other five games were used in the intervention, two as group games and the other three as individual games. Students played the games over a six-week period at the end of their chemistry lesson. The game score and leaderboards were not recorded. They were, however, shown to the students during and at the end of the games. The students could log in and play the past Kahoot! games for practice if they wished.

The students were sent links to two additional games so that they could practice during their mid-semester break that fell during the six-week intervention period, but the focus was on the Kahoot! games. The links are:

i. https://www.math-play.com/Integers-Jeopardy/integers-jeopardy-fun-game_html5.html
ii. https://www.mangahigh.com/en/games/bubblefunction

3.5.3.1 Kahoot! Game Design

Two Chemistry professors informed me about some basic mathematics challenges their students had in the chemistry classroom. They then collaborated and sent me a joint email, informing me of the topics the students were struggling with. These topics included transposing formulae and working with basic mathematical operations, like multiplication and division of scientific notation.

These are mathematics topics that are very important in the chemistry classroom. For example, if a student conducts a chemical reaction that produces a gas, and the student wants to find out the number of moles of gas produced, they could use the ideal gas formula $PV = nRT$. The student could record the room temperature (T) and pressure (P) and measure the volume (V) of the gas that was produced. The student would then be required to transpose the formula above to make n (the number of moles) the subject. The steps involved in transposing the formula are mathematical equation solving techniques where the equation is rearranged by adding, subtracting, multiplying and dividing, to make the desired variable the subject.

Many students could not do these calculations, impacting their progress in the classroom. Their teachers had concerns and wanted them to get help and overcome these challenges.

After receiving the email from the professors, I had further discussions with them and informed them that I could design a basic mathematics review of the pertinent topics and deliver it at the beginning of the upcoming semester. In addition to this, I suggested designing some Kahoot! Games to be used in the classroom to support learning and review throughout the semester. I proposed this idea to the professors to explore the impact of mathematics game-based learning in a higher education classroom. They thought it would be a great idea to do this in their classes since they were genuinely facing an issue and looking for a solution.

I had to work quickly to get everything together before the semester started. I decided to use Kahoot! as the game platform because I was used to using it in my classroom, and I have seen students' positive reactions to it. I had also reviewed literature on the use of Kahoot! to facilitate game-based learning, so I was aware that it was a successful tool.

The professors gave me a thorough list of topics to include in my review, and I designed a PowerPoint presentation, which I presented to the various Chemistry classes of the two professors at the beginning of the semester.

I discussed with one of the professors how the games would be used in the classes, and we agreed that it should be a review at the beginning or the end of the lesson, and not to take up too much time, in other words, short, effective and fun.

As stated above in section 3.5.3, I designed 6 Kahoot! games. One for the students to familiarise themselves with the platform, and the other 5 to be used in the intervention. Two of the five games were designed as group games, so the questions were more challenging, and they got more time to do it.

I had never designed Kahoot! games before; I usually use already existing Kahoot! games. However, this time I wanted to be very targeted and specific. I wanted Kahoot! games tailored to the teachers' requests, so I decided to make my own, with the time specifications, topics and difficulty level recommended by the teachers for their students.

Designing the games was not a difficult task. As a mathematics lecturer, I knew what questions to include, and the games were not long, so that was good. Getting the questions typed up in Word using the equation editor was time-consuming and then cutting and pasting them into Kahoot! While making sure the sizes appear uniform.

Information regarding accessing the games was sent to one of the teachers, and she had a look at the games and gave her feedback. A few minor adjustments were made until the teacher was satisfied with my prepared games.

When the time came for the games to be used in the classrooms after all the ethics and permissions had been cleared, one of the chemistry professors, who is older, said he could not facilitate the games in his class that semester, but he would try in a later semester. The other teacher used the games in the three different classes.

Other elements of my proposed research were discussed with the professor prior to the start of the intervention, such as game design, consent forms and information sheets, pre-test and post-test, questionnaire and focus groups. I worked closely with the professor to ensure the process ran smoothly. The professor continued to use Kahoot! games in her classroom in the semester that followed.

3.5.3.2 Kahoot! Displays

On the question display (see Figure 3.4), the question is at the top with four multiple-choice answers, each embedded within a distinct colour and assigned one of four shapes (triangle, diamond, circle, or square). In this case, there is one correct answer, Kahoot! allows the quiz creator to select one or multiple correct answers. There is a timer on the screen counting down from sixty seconds. Each question was set at sixty seconds when the Kahoot! quiz was created. The thirty-five (35) on the top left of the display screen represents thirty-five seconds left before the time to answer the question elapses.

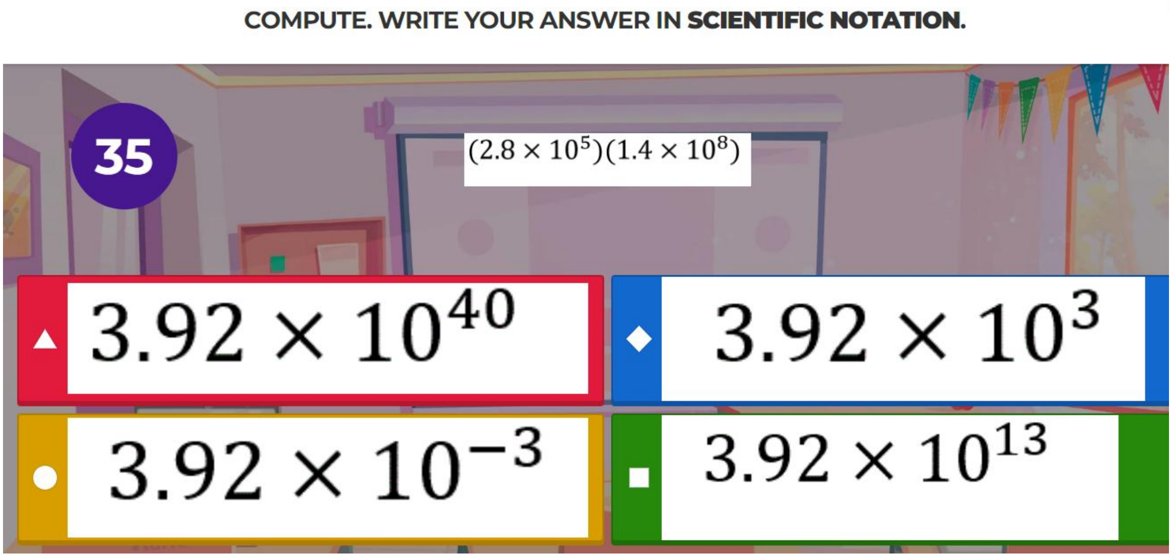

Figure 3. 3 Example of question display on host's screen

The students see four colours with a shape embedded (corresponding to the colours and shapes on the hosts' screen) representing the four multiple-choice answers for the question given on the screen of their device (see Figure 3.5). The student chooses the colour on their screen that corresponds to the answer of their choice shown on the options given on hosts' screen. For example, in Figure 3.4, the correct answer is 3.92×10^{13} which is embedded in the green colour on the hosts' screen. The student would therefore have to choose the green colour on their screen (Figure 3.5) to get the question right.

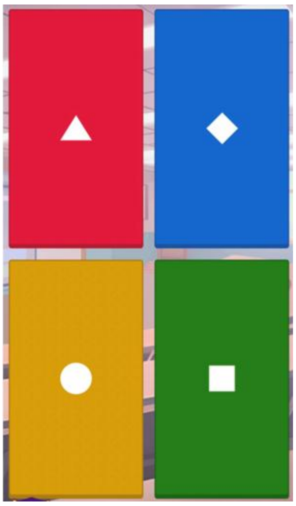

Figure 3. 4 Example of answer choices on user mobile phone screen

After the student selects their answer, they get instant feedback as to whether their choice was right or wrong. After all students have made their choices or after the sixty (60) seconds allocated to each question had elapsed, a leaderboard is displayed on the hosts' screen showing the students' score and position up to that point (see Figure 3.6). The between questions leaderboard shows the top five students. At the end of the game, the top three students can see themselves on a podium (see Figure 3.7). Additionally, the students get to see their final position on their individual devices.

Figure 3. 5 Examples of the leaderboard at the end of a question

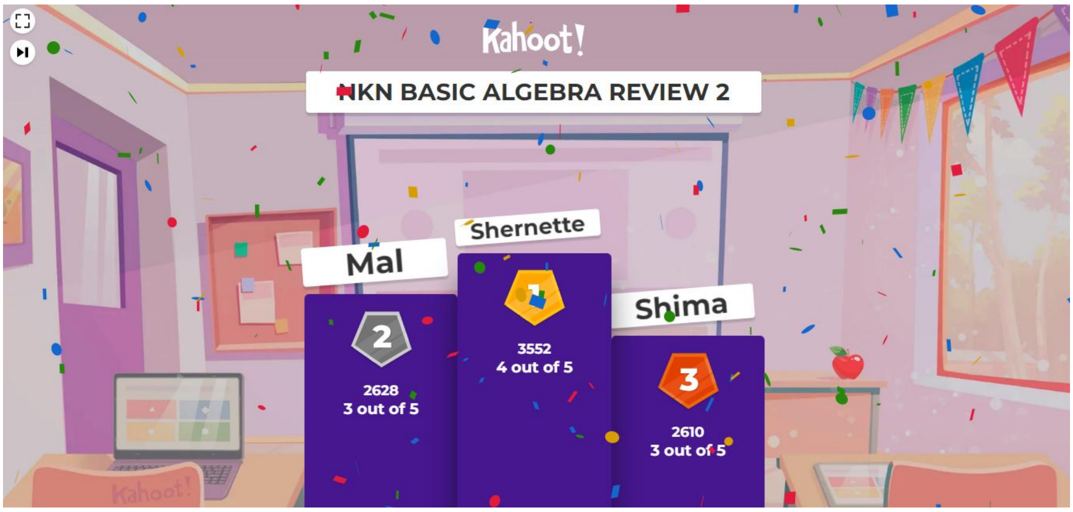

Figure 3. 6 Examples of the leaderboard at the end of the game

3.5.3.3 Kahoot! Game Elements

Kahoot! uses scores and a leaderboard to keep track of players' progress throughout the games. Leaderboards are common in games, sports, and even in classroom settings in some educational contexts; for example, some students are placed on a leaderboard based on their overall performance in a classroom. Leaderboards can provide feedback (usually numerical) on players' points and positions in comparison to other players.

When scores are displayed on a leaderboard, they encourage players to be competitive and interactive (Alaswad et al., 2015). 'Leaderboards provide learners with an opportunity to interact cooperatively, socially, and competitively by engaging them in a community of people with similar interests' (Alaswad et al., 2015, p. 395).

Competitive interaction results when high-achieving students compete for the highest scores, and this, in turn, motivates low-achieving students to propel themselves to earn a position like that of the high achievers. On the other hand, some negative outcomes have been reported with the use of leaderboards in education. With regards to students' learning engagement, it is claimed that students are at first excited but then they may eventually become negatively affected by their place on the leaderboard if they are not among the top achievers (Alaswad et. al., 2015). In my personal experience of working with game-based learning in the mathematics classroom, students demonstrate a high level of engagement and interaction. They are usually competitive and work hard to be placed on the leaderboard.

Feedback was a key game element when the Kahoot! games were being played. The students got instant feedback after answering a question. They were informed whether their answer was right or wrong. When the time allocated to the question had elapsed, or after everyone playing responded to the question, provided this happened before the time for the question elapsed, all students saw the correct answer, how many people chose each answer, and the leaderboard at that time in the game. Other game elements, such as competition, collaboration, interaction, and time, will be discussed in the literature review section.

3.5.4 Coursework Grade

The final coursework grades were also observed and recorded to determine the performance of students who took part in the game-based intervention. The grades of students in previous cohorts from 2017-2022 were obtained and recorded so that they could be compared to the grades of students who did the intervention to see if there was any statistical significance. All previous cohorts used in the study were taught by the same professor who taught the students in the intervention class.

3.5.5 Questionnaire

One week after the intervention was completed, the students were asked to complete an anonymous Qualtrics questionnaire. Questionnaires were administered following the posttest. Students were informed of the questionnaire and were sent an information sheet and consent form. Some students were under 18, and their parents were also sent consent forms. Those students were also given assent forms. I was not present in the classroom at the time of the questionnaire completion. Thirty-eight questionnaire responses were received across all 3 classes. The questionnaire consisted of modified versions of a validated flow (Engeser, 2014) and a modified validated SDT questionnaire (Azadvar et al., 2018), as well as questions involving motivation and game elements, benefits and challenges of the intervention, and participants' demographics. There were 36 Likert-type questions, five open ended questions and three demographics questions. The Likert-type questions were on a 5-point scale with responses ranging from strongly disagree to strongly agree and the questions were based on flow theory, SDT and game element motivation. The open-ended questions were designed to get the students' perception of the benefits and challenges of the intervention. This questionnaire instrument helped to give students a voice and added validity to the process of the game-based intervention. Table 3.1 gives a breakdown of the questions per section, number of questions, question type, and question content.

Sections	**Number of questions**	**Question type**	**Question Content**
Section 1:	7	Likert	Game Elements Motivation
Section 2:	12	Likert	Flow
Section 3:	6	Likert	Autonomy
Section 4:	6	Likert	Competence
Section 5:	5	Likert	Relatedness
Section 6	5	Open-ended	Benefit and Challenges
Section 7	3	Fill in multiple-choice	Demographics
Total	**44**		

Table 3. 2 Questionnaire structure

3.5.6 Focus Group

Three focus groups were conducted with students who chose to participate. Students were asked a series of questions to get more clarity on the responses given to the questionnaires. The first focus group had 10 participants, the second had 10 participants, and the third had 12 participants. They were all conducted on the same day and in the regular class slot for the students, but they were aware that their participation was voluntary, and they did not have to attend the session if they did not want. There was no penalty associated with not participating in the focus group.

3.6 Data Analysis

The data analysis techniques used in this study are a mixture of quantitative and qualitative techniques, given that this study is a mixed methods study using both approaches.

The quantitative data (students' pretest and posttest scores, students' final grades, and Likert questions) were analysed using the SPSS and the Qualtrics software. I used SPSS to run normality tests of the data, compare the means and standard deviation of the pretest and posttest, and conduct a paired samples t-test of their differences. I also used ANOVA to compare the final grades of students in the intervention cohort with students of previous cohorts who studied the same courses as the ones under study. The Qualtrics software gave the mean and standard deviation of the Likert scale data, and the analyses of those questions were produced from the Qualtrics output.

The qualitative data (open-ended questions of the Qualtrics questionnaire, focus group) were analysed using reflexive thematic analysis (Braun & Clarke, 2021). The responses from students were coded, and the themes were constructed through a process of analysis and interpretation of the data, then reported. An overall summary of the students' responses (to the questionnaire and focus group), as well as the themes and quotes of some of their responses to the open-ended questions, are shown in the data analysis chapter.

3.7 Audience

This research has various audiences. Firstly, the results of the intervention will provide helpful insights into the impact of the use of game-based learning in higher education mathematics in the author's context. This will help in lesson planning and execution. Further, even though the intervention is done in a chemistry classroom, the findings may be beneficial to mathematics faculty as well as faculties from other interdisciplinary fields that incorporate mathematics, such as physics, business, and economics. Executive management is also an audience for this intervention and can use findings to inform policy that will enhance the teaching and learning of mathematics. Researchers and students are also audiences, as it can serve as a learning tool for further research.

3.8 Ethical Considerations

The intervention was conducted in classrooms other than my own. Students were informed that their participation (or not) in the research would have no implication on their academic outcome in the sense that they would not be penalised or rewarded for their non-participation or participation. Participation here means completing questionnaires and/or a focus group and giving permission for their grades to be used.

3.8.1 Permission

Permission to conduct this research was sought and granted. Lancaster ethics application was submitted on January 17, 2023, and approval was received on January 31, 2023. The University College of the Cayman Islands ethics application was submitted on January 24, 2023, and approval was received on February 9, 2023.

3.8.2 Informed Consent

An Information sheet, assent (under 18), and consent form were given to all participants (and parents for those participants that are under 18). The participants were informed at the beginning of the survey that by completing the survey, they consented to their contribution being utilized in a research project. As this intervention was being conducted as a teaching strategy built into the class activities, consent here refers to the student agreeing to respond to the questionnaire (and/or focus group) and permitting their grades to be used in the research study.

3.8.3 Voluntary Participation

If the student changed his/her mind, they were free to withdraw within two weeks after participating. If the student wanted to withdraw, they would let their class teacher know, and I would extract any ideas or information they contributed to the study and destroy them. However, it would not have been possible to withdraw the questionnaires since they were anonymous, and I would not have been able to identify participants' individual responses since they were pooled with the responses of other participants. Similarly, it would not be possible to extract an individual's contribution to a focus group discussion as it is part of an ongoing conversation; however, I would do my best to disregard the contribution. No student opted to withdraw the data they contributed. A few students from the class opted not to participate at all.

3.8.4 Confidentiality

Questionnaires were anonymous. There was no way of identifying a particular student based on a completed survey. Furthermore, pseudonyms have been assigned to participants so that when findings are presented/reported, students cannot be identified. If students revealed any identifying data in open-ended questions, these were anonymised and not included in the report. The names of students were removed from the pretest, posttest, and course grades and replaced with a labelling number by their class teacher. For example, student 1, student 2, etc., but student 1 from the pretest was the same as student 1 in the posttest, making it easy to compare from the pretest to the posttest. There was no need to match questionnaires with pretest, posttest, and course grades.

It is not possible to guarantee confidentiality within a focus group discussion, bearing in mind that various students are present. However, the participants were reminded at the start of the group interviews that there would be no identifiers linking them to their comments in the final report.

Participants were aware that their participation in the focus group was optional. The audio recordings of the interviews were transcribed, and information identifying the institution or individuals was removed or changed so that confidentiality was maintained as much as possible.

Participants have full protection of the UK Data Protection Act and GDPR. The completion of this study is estimated to be in the summer of 2024. Data will only be accessed by myself and (only if necessary) my supervisor, Julie-Ann Sime. The research may be used for journal articles, conference presentations, and PhD thesis.

3.8.5 Privacy and Data Storage

'Data' here refers to the researcher's notes, survey results, audio recordings, and any email exchanges we may have had. The data may be securely stored for ten years after the successful completion of the PhD Viva as per Lancaster University requirements, and after that, any personal data will be destroyed. Audio recordings will be transferred and stored on my personal laptop and deleted from portable media. The laptop will be encrypted, and as soon as possible, the data will be transferred to Lancaster University's secure OneDrive account and deleted from the laptop. I will ensure that portable devices are kept safe until the data is transferred from them and deleted. Audio recordings of focus group discussions will be taken and then transcribed by me. Audio recordings of focus groups will be immediately transferred off mobile devices, transcribed, and the recording destroyed.

3.9 Validity and Reliability

Reliability and validity in quantitative and qualitative research are seen through different lenses, and not all researchers agree with what constitutes reliability and validity or whether both may be applied to the quantitative and qualitative research strands.

Despite this, one prominent school of thought on the subject of reliability and validity in quantitative research is reflected here by Golafshani (2003), who posits that reliability and validity in quantitative research comprises two components, firstly whether the results of an experiment are replicable (and hence reliable) and secondly whether the measuring techniques are accurate and effective in measuring the intended variable (validity).

On the other hand, reliability and validity in qualitative research are 'conceptualized as trustworthiness, rigor and quality' (Golafshani, 2003, p. 604). Triangulation may complement the efforts of achieving validity in qualitative research (Thurmond, 2001).

To enhance the validity and reliability of the study, several steps were taken. For one, the instruments used to collect the pretest and posttest data were modified versions of the validated MUST test with KR-21 = 0.821 (Petros et al., 2018). The KR-21 (Kuder-Richardson Formula 21) is a measure of reliability that ranges from 0 to 1. Measures above 0.8 to 0.89 are considered good, and above 0.9 is considered excellent (Balasubramanian & Sudha Rani, 2023). Using a previously validated instrument has advantages such as expert preparation and evaluation of the instrument, contributing to its quality and reliability, saving time, and conserving resources (Elangovan & Sundaravel, 2021.)

The questionnaire tools that were used are also modified versions of validated instruments: 'The Flow Short Scale has been validated by Rheinberg et al. (2003) and by Engeser & Rheinberg (2008). The internal consistency reliability was reported to be $\propto = .92$ for the flow factor' (Kyriazos et al., 2018, p. 1362). The Cronbach's alpha used to measure the internal reliability is on a scale of 0 to 1, with acceptable values reported to range between 0.70 and 0.95 (Tavakol & Dennick, 2011). A value of $\propto = .92$ is suggesting excellent internal consistency; that is, collectively, the items of the questionnaire instruments represent a good measure of the intended variable.

The Cronbach's alpha and Rasch reliability tests were used to assess the reliability of the SDT instrument. The Cronbach alpha for the full SDT scale was $\propto = .91$, and the alpha values for subsections of the SDT were also calculated. For the autonomy section, the score was $\propto = .86$, for the competence section, the score was $\propto = .82$ and for the relatedness section, the score was $\propto = .84$. All the alpha values of the SDT, the instrument, and the respective sections (autonomy, competence, relatedness) have values indicating good and excellent internal consistency.

When it came to marking the students' scores in the MUST test, a second faculty member was asked to mark the test along with me. Having a second investigator can reduce the potential for bias, improve accuracy and consistency, and increase validity and reliability (Thurmond, 2001). In this research, the faculty investigator and I discussed discrepancies where they existed and arrived at a consensus before making a final decision. This added rigor and transparency to the entire process.

We marked the tests separately and then recorded our scores for each student on an Excel spreadsheet. If a score did not agree with a particular student, then the Excel spreadsheet would output a difference value that is not zero. When that happened, we would both revisit the student script to see what was causing the difference in our assigned score. We then discussed the discrepancy, re-mark where necessary, and input the score that corresponds. In the end, all the marks we assigned to the students for the pretest and posttest corresponded, and there was no difference in the final score we gave each student.

The data obtained from the open-ended questions were all recorded on a spreadsheet. I then read each response and compared them to the original questionnaire responses to ensure that the details on the spreadsheet were accurate. I checked off each response on both the spreadsheet and the original questionnaire response after reviewing it to ensure that all responses were accurate and accounted for. The data was then analysed using reflective thematic analysis. Following a series of set procedures in organising and analysing the data enhanced the consistency and reliability of the results obtained from the data. Additionally, my insiderness contributed to the accuracy and reliability of the data interpretation, as I was clear on the points the students articulated, and I could place them easily in the context of the mathematics GBL intervention, being a mathematics lecturer who was familiar with using the Kahoot! platform with my students.

The focus group data were recorded on TEAMS, and transcriptions of the sessions were obtained. Some of the scripts in the initial transcription generated by TEAMS were not clear, so the original recording was replayed several times to correct the errors in the original transcription. The process of verifying the correct transcription was meticulous but necessary.

I wanted to ensure that the final transcription was a true reflection of the original audio to ensure the reliability of the results. When I was confident that the transcription was accurate, it was ready for analysis. The focus groups were also analysed using reflective thematic analysis.

In conclusion, regarding the replicability of this study, given that we are dealing with human participants, though in a given context, external factors and experiences may influence their responses from one time to the next, I think the overarching themes will remain.

I am confident that the methods and instruments explored the research questions and were able to provide adequate answers. Approaches such as triangulation and other efforts to improve accuracy were taken to facilitate a more rigorous and trustworthy study.

3.9.1 Insiderness and Outsiderness

Mercer (2007) argues that 'insiderness and outsiderness are better understood in terms of a continuum rather than a dichotomy' (Mercer, 2007. p.3). For example, in the context of the intervention, it is possible to see me as an 'insider' in the sense that I share the same institution as the participants and I was part of the process of delivering the mathematics review at the beginning of the intervention, marking the pretest and posttests and analysing and interpreting the data, in contrast, I may also be viewed as an outsider, in the sense that the participants are the students and I am not their lecturer. I think my position as an insider researcher, in this instance, adds value to the research process; as Mercer (2007) posits, an insider researcher 'often enjoy freer access, stronger rapport and a deeper, more readily available frame of shared reference with which to interpret the data they collect' (Mercer, 2007. p. 13). As an insider and lecturer in the study university, the chemistry students were accessible to me for my research. Also, I knew the mathematics involved in chemistry and was able to design the mathematics review and Kahoot! games. In all this, I acknowledge the issue of researcher bias (Fleming, 2018). However, steps were taken to mitigate potential biases, such as using a second marker for the pretests and posttests, getting another faculty member to conduct the focus group interviews, and distributing links for the questionnaire. These steps also add to the validity and reliability of the research process.

3.10 Triangulation

There are several interpretations of triangulation. Triangulation comprises the amalgamation of sources of data, investigator's participation, methodological approaches, theoretical lens, and methods and techniques of analysis (Thurmond, 2001).

A researcher may choose to use one or multiple approaches to triangulation (Thurmond, 2001). In this study, I used multiple triangulation techniques to enhance the study's reliability and validity (Bans-Akutey & Tiimub, 2021)

Firstly, the study investigates the impact of game-based learning from two different theoretical perspectives (theoretical triangulation), mixing quantitative and qualitative methodologies (methodological triangulation) while employing various data collection techniques (data triangulation). Additionally, the data was collected with the assistance of another faculty member (investigator triangulation), and a portion of the data analysis process, which involved marking the pretest and posttest and making sure the grades were accurate, was done with two separate faculty members (analytical triangulation).

In addition to enhancing the reliability and validity (Creswell & David Creswell, 2018) of research design, triangulation also reduces bias and provides a more comprehensive understanding of the research problem in the study (Thurmond, 2001) by, for example, mixing qualitative and quantitative methods.

3.11 Concluding Remarks

This chapter started out by highlighting the research questions and the problem statement. It then discussed the research approach that was employed to answer the research questions. From a standpoint of pragmatism, mixed methods were used to explore a mathematics game-based learning intervention. Triangulation of research tools and methods was utilized in this intervention, some quantitative and some qualitative. Several game elements were explored in the intervention, including leaderboards, points, feedback, and competition. Methods that will be used to analyse the data were discussed in this chapter. Data protection, confidentiality protocols, ethical considerations, and limitations were also discussed.

4 Results and Findings

4.1 Introduction

In this study, I set out to answer four research questions centred around investigating the impact of mathematics game-based learning in a higher education setting. The research questions investigated students' overall performance after a mathematics game-based intervention was conducted in their chemistry classroom, their perception of flow, autonomy, competence, and relatedness, as well as their perceptions of the benefits and challenges of mathematics game-based learning. This is a mixed methods study, and both quantitative and qualitative data were collected over one semester spanning four months. The data collection instruments were an anonymous questionnaire including Likert-type and open-ended questions; three focus groups; pretest and posttest MUST (Math-Up Skills Test) tests; the final grades of the students that participated in the intervention; and the final grades of students of previous cohorts that did not participate in the intervention, whose grades were obtained for comparison purposes. The results obtained from the data collection were analysed using several methods, including thematic analysis for the qualitative data and ANOVA and t-tests for the quantitative data. The data analysis section is a very crucial segment of the research study as it makes sense of the data collected and facilitates responses to the research questions. Quantitative and qualitative analytical techniques synergise to interpret the data and provide a holistic insight while adhering to principles that ensure the reliability, validity, consistency, and robustness of the results.

4.2 Demographics of Research Participants

The participants in this study were from three classes. There were students studying chemistry at the bachelor's degree level aged between 16 and 41. A total of 43 participants accessed the questionnaire; however, 38 of them gave responses to the questions. Of the 43 participants who accessed the questionnaire, 10 of them used the anonymous survey link, while the remaining 33 participants used the QR Code that was provided to them. A total of 32 respondents participated in the focus groups across the three classes, and 39 students completed the pretest and posttests overall.

4.2.1 Participant Age (questionnaire)

Even though there was an overall total of 38 participants in the questionnaire, only 36 responded to the question about their age, (see Table 4.1).

Age	**Number of Students**	**Percentage (%)**
16	3	8
17	10	26
18	11	29
19	5	13
20	3	8
21	1	3
22	2	5
41	1	3
Age not given	2	5
Total	**38**	**100**

Table 4. 1 Participant age

4.2.2 Participant Gender Identity (questionnaire)

Participants were from three gender identities, namely, male, female, and non-binary or a third gender. Most of the participants, 22 (61%), were female, while 12 (33%) were male. One participant did not declare his/her gender identity and one participant was from a third gender, (see Table 4.2).

Gender	**Number of Students**	**Percentage (%)**
Male	12	33
Female	22	61
Non-binary/ 3rd gender	1	3
Prefer not to say	1	3
Total	**36**	**100**

Table 4. 2 Participant gender identity

4.2.3 Participant by Course (questionnaire)

The participants in the questionnaire were from two courses, two sections of General Chemistry I (CHE 111) and one section of General Chemistry II (CHE 112). Twenty-three (60%) of the participants were from general chemistry I, while the other 11(29%) were from general chemistry II. The remaining four (11%) did not state which section they were from (see Figure 4.1).

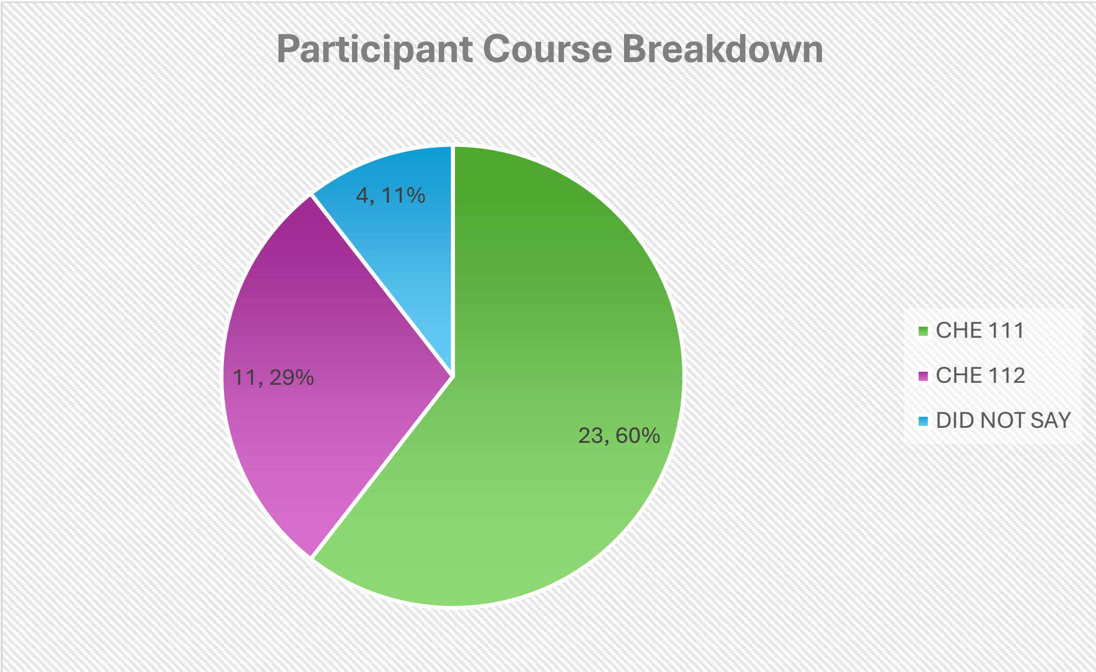

Figure 4. 1 Pie chart of participant course breakdown

4.2.4 Focus Group Participants

There was a total of 32 participants across the three focus groups. In the table below, the focus groups are arbitrarily labeled 1, 2, and 3, representing the three classes in the study. Most participants in the focus groups attended face-to-face, but two attended online via Microsoft TEAMS, (see Figure 4.2).

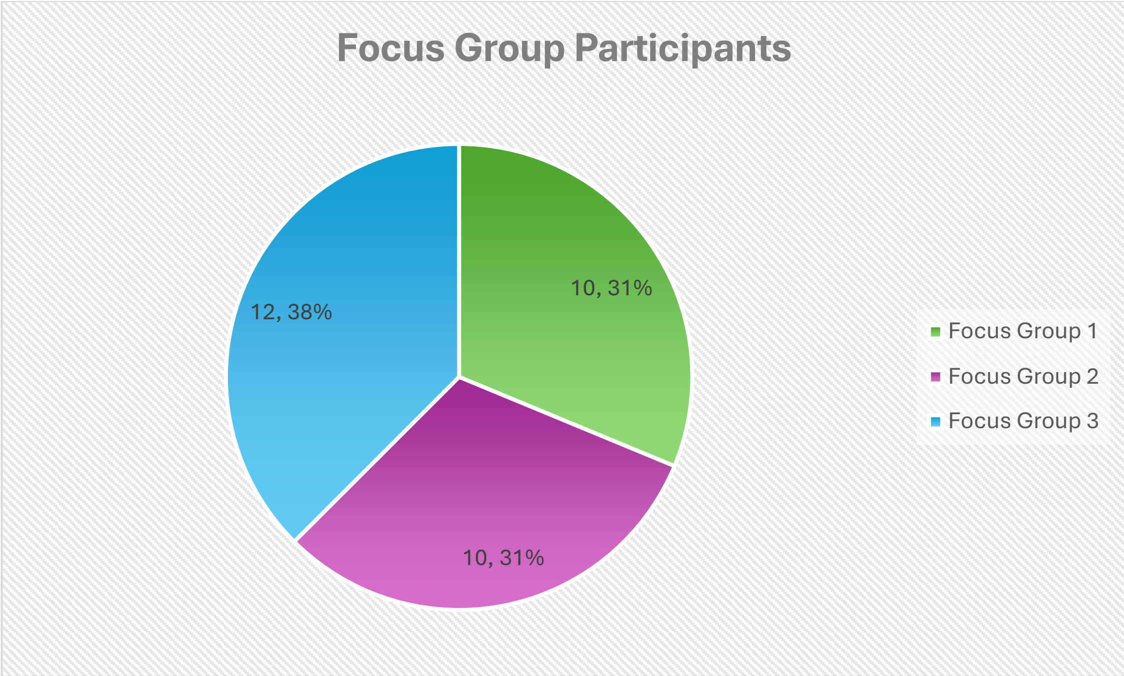

Figure 4. 2 Pie chart of focus group participants

4.3 Answering the Research Questions

The research questions will be answered in chronological order using results from the data collection instruments. As previously mentioned, the data collection tools include an anonymous questionnaire, three focus groups, two validated MUST tests used as the pretest and posttest, students' final grades as well as the grades of students of previous cohorts that studied the same courses as the students in the intervention courses, (see Table 4.3). These intervention courses and the courses of students of the precious cohorts were both taught by the same teacher.

Research Question	Data Collected
RQ1	Pretest score, posttest score, final grades of intervention students, final grades of students of previous cohorts
RQ2	Likert questionnaire responses
RQ3	Likert questionnaire responses
RQ4	Open-ended questionnaire responses, focus group responses

Table 4. 3 Research question and type of data collected

4.3.1 Answering Research Question 1

RQ 1: To what extent does mathematics game-based learning impact students' academic performance?

To answer this research question, primary and secondary data were collected. The primary data collected were a pretest and posttest from the three separate groups of students that participated in the research study as well as the students' final grades. The secondary data obtained were the grades of students from previous cohorts who did not take part in a game-based intervention but were taught using the traditional method.

I will answer research question 1 in four steps. I will first compare and examine the nature of the pretest and posttest data obtained (step 1). I will then analyse the difference scores and run a paired samples t-test on the pretest and posttest (step 2). Thirdly, I will compare the grades of students of previous cohorts to the grades of students in the intervention cohort (step 3). Finally, I will write a summary of the findings of research question 1 (step 4).

Step 1

4.3.1.1 Comparing the Changes from Pretest to Posttest MUST Test

The instruments that were used as the pretest and posttest were two versions of the MUST tests. As stated previously, the MUST tests are validated instruments with a KR-21 score of 0.821, this number represents a good value for the instrument's reliability. It is important to note that there was no statistical difference between the versions (Petros et al., 2018), and hence, they are comparable.

A total of 39 students took the pretest and posttest. When the data from the pretest and posttest were compared, it was found that 27 (69%) of the students improved their score from pretest to posttest, nine (23%) decreased their score, and three (8%) maintained the same score from pretest to posttest, (see Figure 4.3). Of the students who increased their scores, the highest gain was plus seven points from the pretest to the posttest; of those who decreased their score from the pretest to the posttest, the lowest decrease was minus three points. There was an overall mean of 1.44 for the difference scores.

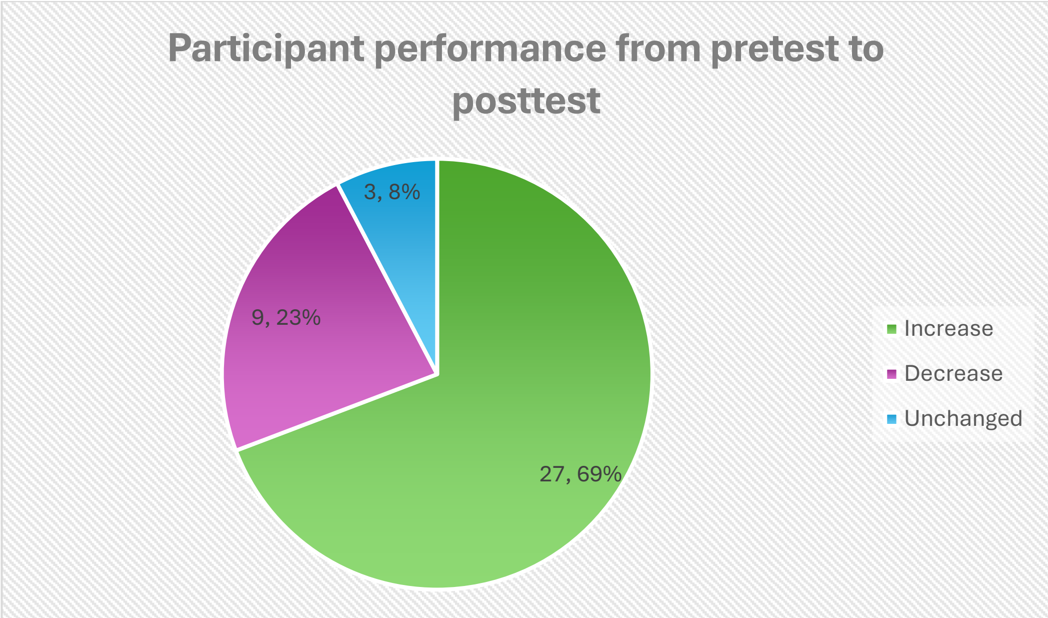

Figure 4. 3 Pie chart of participant performance from pretest to posttest

4.3.1.2 Descriptive Statistics of the Data

The pretest scores had an overall mean of 9.49, while the posttest had a mean of 10.92. This means that the posttest mean is higher than the pretest mean. The standard deviation for the pretest is 2.644, and for the posttest, it is 2.421. Both data sets had similar variability. The posttest had a higher minimum (5) value than the pretest but a lower maximum value (14) overall. Both pretest and posttest were marked out of 15. For the 25th, 50th, and 75th percentile, the posttest had higher scores when compared to the pretest; this suggests that the values of the posttest are higher than the values of the pretest in general, (see Table 4.4).

	Mean	**Std. Deviation**	**Minimum**	**Maximum**	**25th Percentile**	**50th Percentile**	**75th Percentile**
Pretest	9.49	2.644	2	15	8.00	9.00	11.00
Posttest	10.92	2.421	5	14	9.00	11.00	13.00

Table 4. 4 Descriptive statistics of pretest and posttest data

4.3.1.3 Normality of the Pretest and Posttest

After initial normality tests of the pretests and posttests (N=39 pairs) were conducted in SPSS, using the Kolmogorov-Smirnov and the Shapiro-Wilk normality tests, it was determined that the pretest data appeared to be normally distributed, but the posttest data did not appear normally distributed. Pretest data had a significance value of 0.062 for the Kolmogorov-Smirnov test and 0.264 for the Shapiro-Wilk, (see Table 4.5). The significance values of both normality tests are greater than the alpha value of 0.05. It can, therefore, be concluded that we fail to reject the null hypothesis; that is, the data set of the pretest is assumed to be normally distributed.

Posttest data, on the other hand, had a significance value of 0.021 for the Kolmogorov-Smirnov and 0.013 for the Shapiro-Wilk. The significant values for both tests were less than the alpha value of 0.05 (see Table 4.5). In this case, we reject the null hypothesis and assume that the data set for the posttest is not normally distributed.

When exploring normally, it is good practice to observe several measures and displays; that way, the validity of the conclusion holds more credibility. With this in mind, I decided to explore the data in a bit more detail by observing output values for skewness and kurtosis as well as the graphs of their histogram, QQ-Plot, and box plot to get a better understanding of the data set and to possibly ascertain the reason for the digression from normality of the pretest data.

	Kolmogorov-Smirnov Significance	**Shapiro-Wilk Significance**
Pretest	.062	.264
Posttest	.021*	.013*

Table 4. 5 Results of Kolmogorov-Smirnov and Shapiro-Wilk normality tests ($\propto = 0.05$)

4.3.1.4 Comparing the Skewness and Kurtosis of the Pretest and Posttest

Skewness and kurtosis both refer to the shape of a distribution. Skewness is a measure of the distribution's symmetry, while kurtosis measures the tallness or flatness of the peak of the distribution. For normal distributions, the skewness is zero, and the kurtosis is three (Siraj-Ud-Doulah, 2021).

The pretest data value for skewness was -.156, and for kurtosis .749, (see Table 4.6). The value for the skewness suggests that the data set is slightly negatively skewed; this means that the tail of the distribution is a little longer on the left-hand side. Since the value for skewness is not very high, it means that the distribution is not significantly skewed and so, this data set may be considered approximately symmetric, that is, approximately normally distributed. The value for kurtosis suggests that the distribution has a peak, although it is flatter than that of a normal distribution.

The posttest data value for skewness was -.668 and for kurtosis -.366, (see Table 4.6). These values suggest that the data set is negatively skewed (a bit more so than the pretest data), and the peak of the distribution is flatter at the top when compared to normal distributions. The -.366 value for kurtosis also suggests that this curve has a flatter top than that of the pretest data. The combination of negative skewness and kurtosis indicates that the posttest data digresses from what is considered a normally distributed data set; however, this deviation is not large.

The findings from the interpretation of the skewness and kurtosis parallel the conclusion above when the Kolmogorov-Smirnov and Shapiro-Wilk normality tests results were interpreted where the pretest is concerned, that is, the pretest appears approximately normally distributed. For the posttest, after examination of the skewness and kurtosis values it was determined that the posttest may also be considered an approximately normally distributed data set after all, though the pretest appears to be a closer 'match.'

The mean and variance are measures of central tendency and variation, respectively. They are both sensitive to outliers. Skewness and kurtosis are measures that are calculated using the mean and variance and so are also sensitive to outliers (Siraj-Ud-

Doulah, 2021). Consequently, I will now examine the graphs of the pretest and posttest, including the box plots, to see the shape of the distribution and to see if there are any outliers present and whether this could be the reason for the posttest and, to a lesser extent, the pretest, divergence from the normal distribution.

	Skewness	**Kurtosis**
Pretest	-.156	.749
Posttest	-.668	-.366

Table 4. 6 Skewness and kurtosis for pretest and posttest

4.3.1.5 Comparing the Histogram of Pretest and Posttest Data

The histogram gives a visual perspective of the shape of a distribution and can help you assess whether the distribution appears normally distributed or not. The histogram considers several statistical measures consolidating measures of central tendencies, measures of spread, skewness, and presence of outliers (Öztuna et al., 2006) into one graph. A normal distribution is perfectly symmetrical. There is no difference between the left- and right-hand side of the curve with the mean, mode, and median at the same point (Hassan & Shkak, 2020). The histogram for the pretest data (see Figure 4.4) appears more symmetric than the histogram for the posttest (see Figure 4.5); this is consistent with the observation for the normality tests as well as the observation of the skewness and kurtosis values. While the posttest data has an obvious left skew, the deviation that results may still be considered that of an appropriately normally distributed data set.

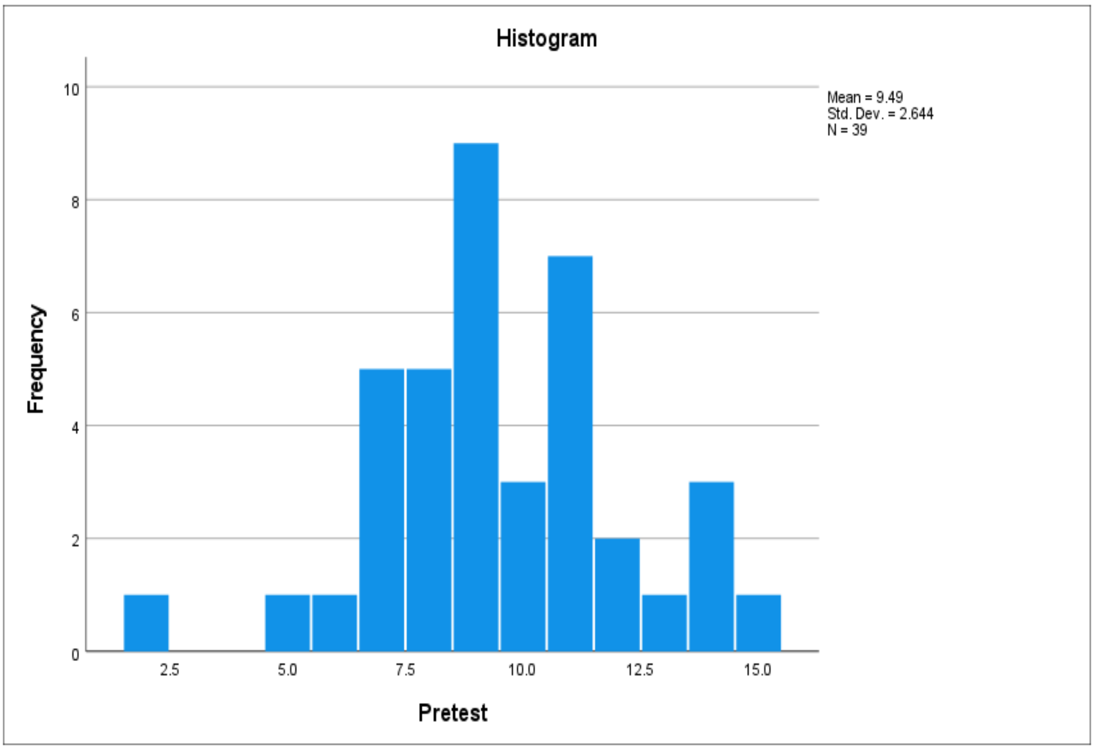

Figure 4. 4 Histogram of pretest

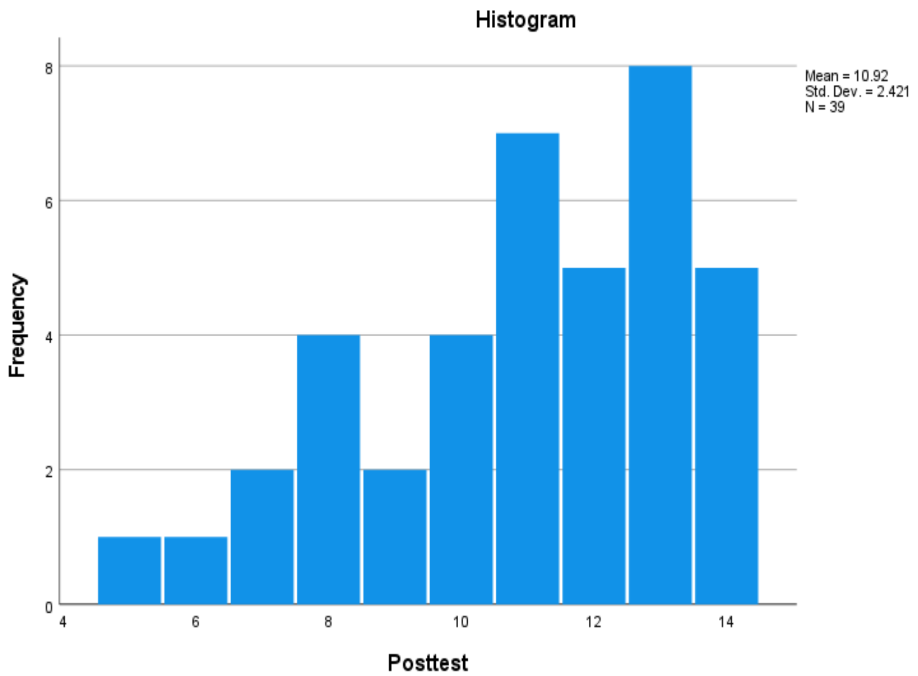

Figure 4. 5 Histogram of posttest

4.3.1.6 Comparing the Normal Q-Q Plot of Pretest and Posttest

The normal Q-Q plot may be used to show how a data set differs from one that is normally distributed by comparing the quantiles of their distributions on a graph (Öztuna, et. al., 2006). On the comparison graph, the expected normal distribution is plotted against the observed normal distribution. 'For values sampled from a normal distribution, the normal Q-Q plot has the points all lying on or near the straight line drawn through the middle half of the points. Scattered points lying away from the line are suspected outliers that may cause the sample to fail a normality test' (Öztuna et al., 2006, pp. 172-173).

From the normal Q-Q plot of the pretest data, (see Figure 4.6), most of the points are on or near to the normal distribution line. There is one point away from the line, and this may be a suspected outlier. The presence of a suspected outlier may lend credence to the data set deviating slightly from the normal distribution. The findings from observation of the normal Q-Q plot are consistent with what was observed above from the Kolmogorov-Smirnov and Shapiro-Wilk Normality tests, the skewness and kurtosis results, as well as the outputs from the histograms, that is, the data set appears approximately normally distributed.

For the graph of the normal Q-Q plot of the posttest data, (see Figure 4.7), the points are not as close to the normal line as those of the pretest data but, at the same time, not far off in such a way to say the data set is not approximately normally distributed. The graph also indicates a possible outlier, which could potentially explain the digression from the normal distribution.

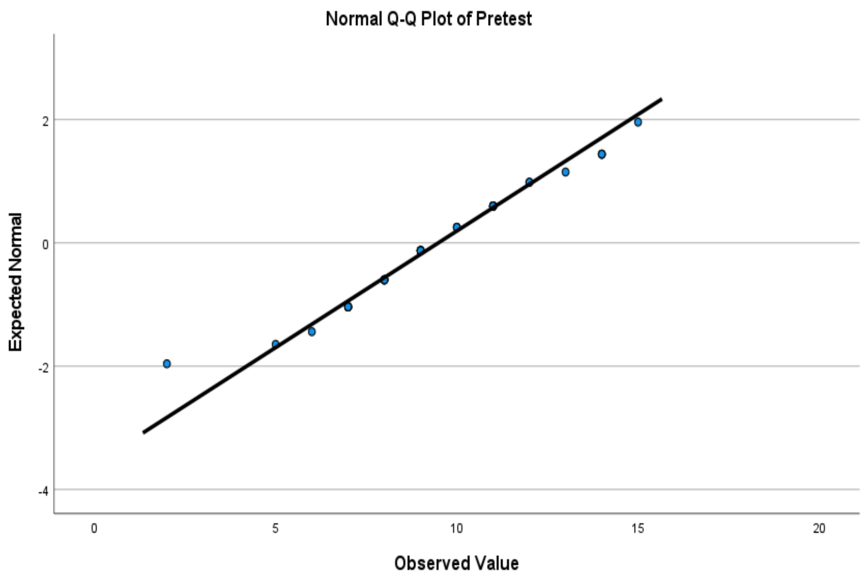

Figure 4. 6 Q-Q plot of pretest scores

From the observation of both normal Q-Q plots, both data sets appear approximately normally distributed, although the pretest appears to be a closer match to the normal distribution. Additionally, both pretest and posttest normal Q-Q plots show potential outliers, which could explain the deviation from the normal distribution.

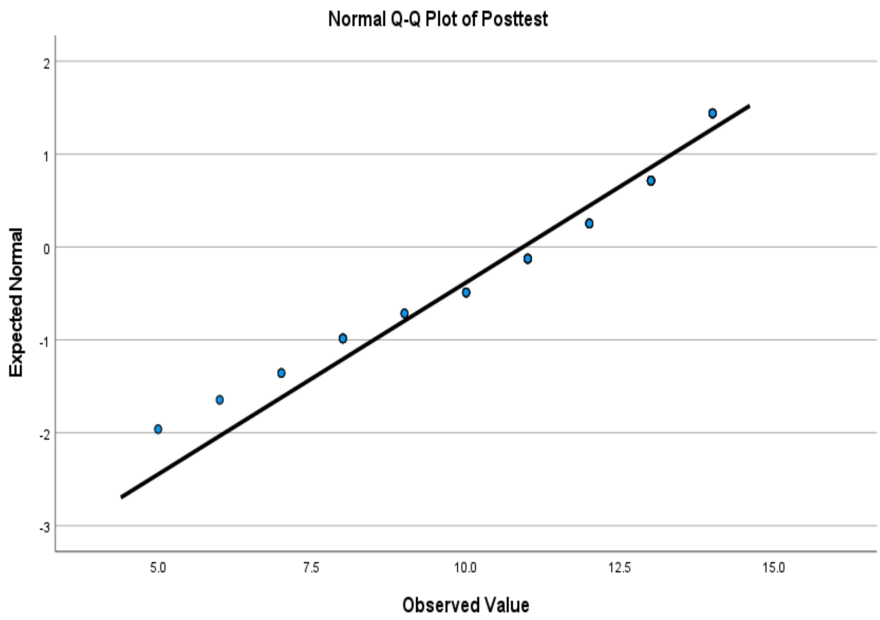

Figure 4. 7 Q-Q plot of posttest scores

4.3.1.7 Comparing the Boxplot of the Pretest and Posttest Data

A boxplot is a visual display that gives a 5-number summary (minimum value, first quartile, second quartile, third quartile, maximum value). Potential outliers are represented on the boxplot with a circle or cross (Öztuna et al., 2006). The boxplot for the pretest data shows one potential outlier indicated by a circle with the number 23 to its top right (see Figure 4.8). This means that there is a potential mild outlier in the data set. The box plot for the posttest data shows no potential outlier, although there were indications of the presence of an outlier when the normal QQ plot was observed. The maximum value for the pretest data is 15, while the maximum value for the posttest is 14, as previously mentioned. The minimum value on the box plot for the pretest data set is five (bearing in mind that there is a potential outlier value of two that is, in fact, the lowest value in the data set). The minimum value on the boxplot for the posttest data set is also five, which is the lowest value in the data set.

The pretest has a median of about 8. The posttest has a median of about 11. The posttest has a higher value for the median than the pretest. This indicates that the posttest data has higher values than the pretest data. The median is also not sensitive to outliers, so it is a good measure of central tendency in this regard, given that there is the presence of outliers in the data set.

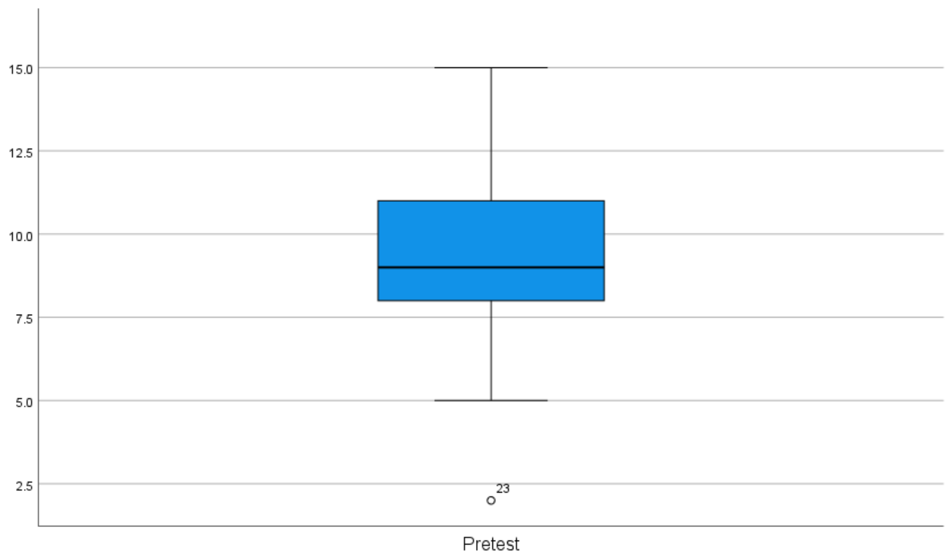

Figure 4. 8 Boxplot of pretest data

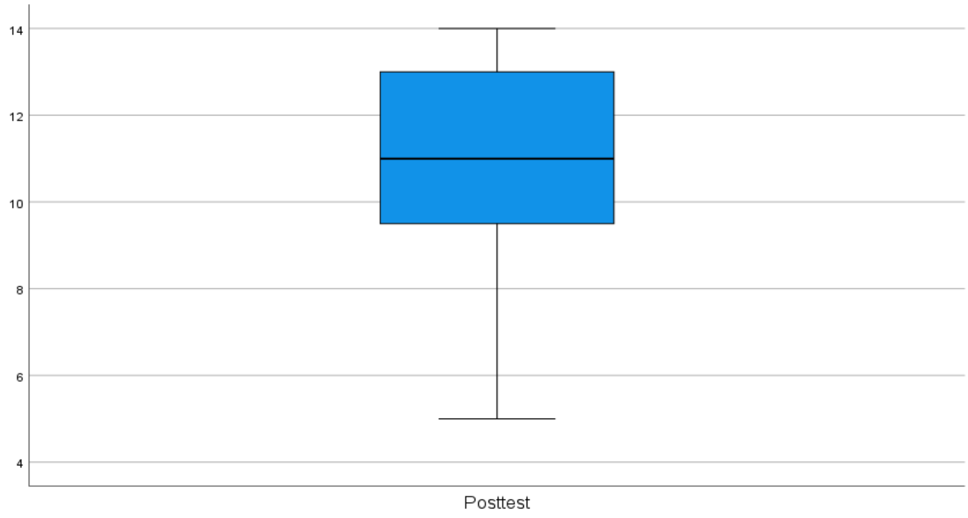

Figure 4. 9 Boxplot of posttest data

4.3.1.8 Summary of the Comparison of the Pretest and Posttest

Considering all the normality tests above, it is concluded that both pretest data and posttest data are approximately normally distributed. Despite the presence of skewness and kurtosis and deviations apparent from the histograms and Q-Q plots, neither data set has extreme deviations from the normal distribution. Therefore, it may be concluded that both data sets are approximately normally distributed.

Step 2

4.3.1.9 Normality Tests for the Differences Scores

For a sample size of N=39, a normality test for the differences of the pretest and posttest was conducted. The value for the Kolmogorov-Smirnov was .160, and the value for the Shapiro-Wilk was .461, (see Table 4.7). This suggests that the data is normally distributed since the significance values for both normality tests are greater than the alpha value of 0.05. Additionally, the value for the skewness was .052, and the value for kurtosis was -.171, (see Table 4.7), further suggesting that the data set of the differences of pretests to posttest is normally distributed.

Kolmogorov-Smirnov Significance	Shapiro-Wilk Significance	Skewness	Kurtosis
.160	.461	.052	-.171

Table 4. 7 Results of Kolmogorov-Smirnov & Shapiro-Wilk normality tests of differences, skewness, and kurtosis ($\propto = 0.05$).

The histogram below, (see Figure 4.10) is approximately bell-shaped, and the points on the QQ-plot, (see Figure 4.11) are close to the normal distribution line.

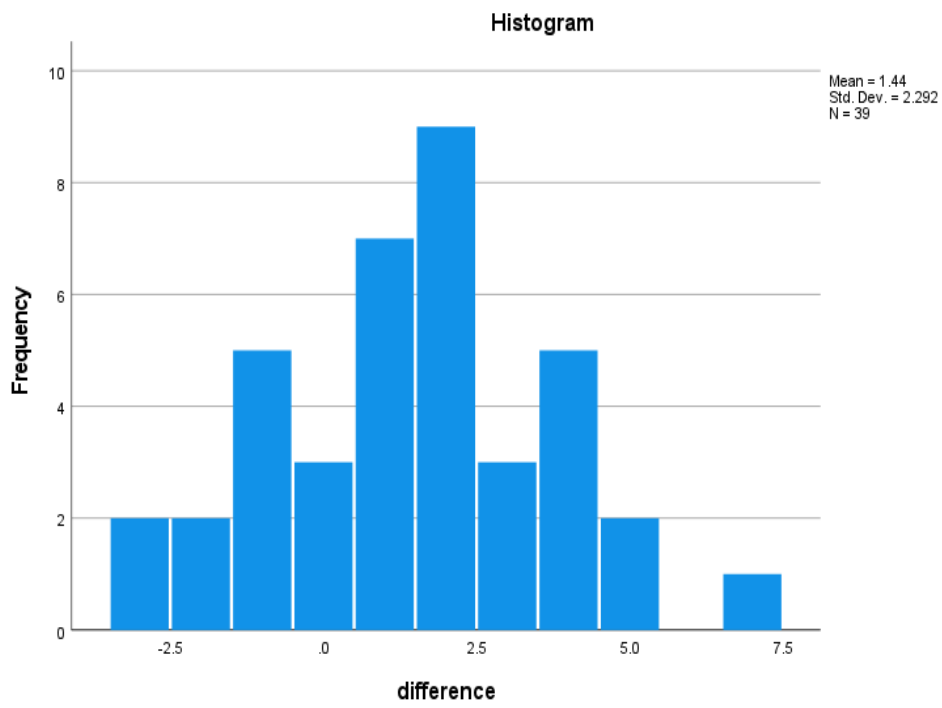

Figure 4. 10 Histogram of pretest to posttest differences

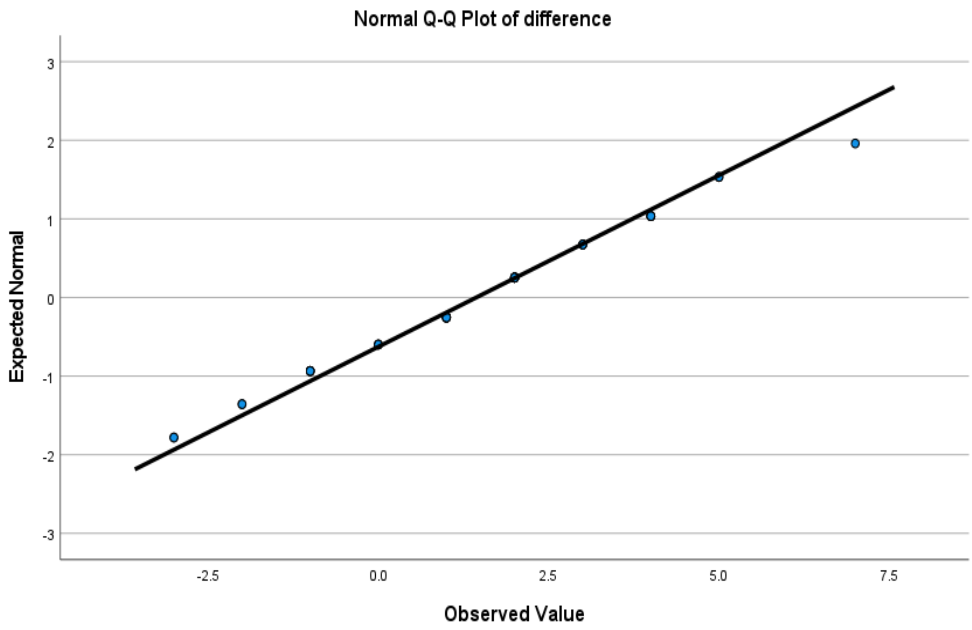

Figure 4. 11 Q-Q plot of pretest to posttest differences

In conclusion, the data set of the differences appears to be normally distributed when both statistical values and graphical displays have been observed. Additionally, from observation of the box plot, no outliers have been identified in the differences data set, (see Figure 4.12).

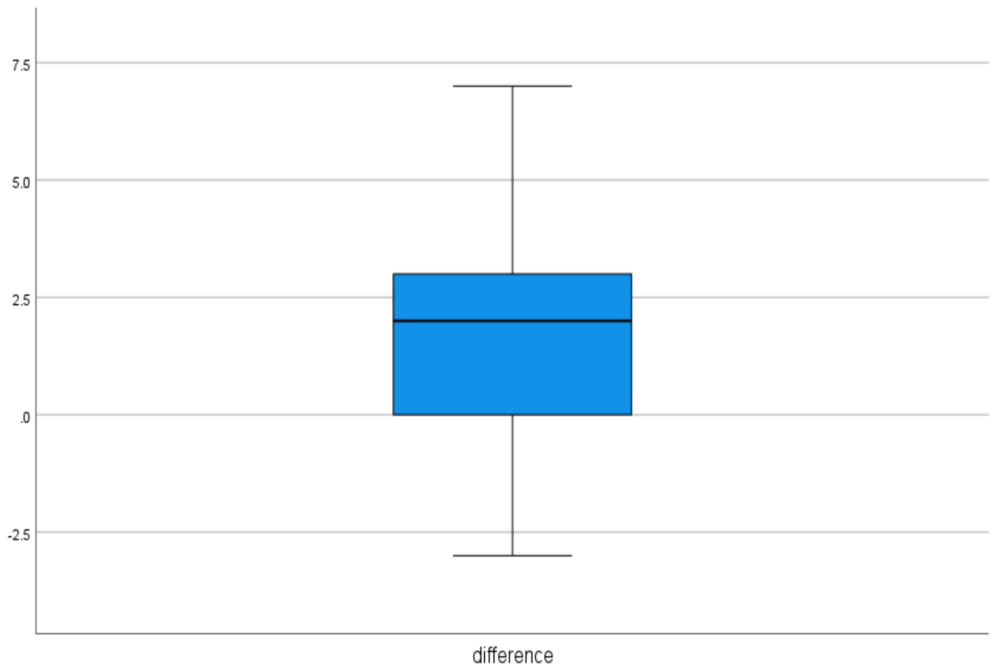

Figure 4. 12 Boxplot of pretest to posttest differences

4.3.1.10 Paired Samples T-Test Assumptions

A paired samples t-test, also known as a paired t-test (among other names), was used to compare the means of the pretest and posttest. A paired samples t-test may be used to compare the means of two groups when each participant in the groups provides two data points (Christopher, 2020). In this study, each student participant completed a pretest followed by a posttest.

The paired t-test is valid as all the assumptions have been met: the scores of the pretest and posttest are on an interval level of measurement and hence a continuous scale; there are two groups representing matched pairs (pretest and posttest score of each participant); there are no major outliers in the data set (this has been shown above); the differences of the pretest and posttest are approximately normally distributed, (see Figure 4.10, 4.11 and Table 4.6, 4.7) (Fein et. 2022, p. 25).

4.3.1.11 Hypotheses for the Paired Samples T-Test

A two-tailed paired samples t-test was done in SPSS on sample size N=39 (pairs). The hypothesis was that the game-based learning intervention resulted in a change in the students' performance from the pretest to the posttest. The null hypothesis states that there is no significant difference between the mean scores of the pretest and posttest, while the alternative hypothesis states that there is a significant difference between the pretest and posttest means (below).

Hypotheses:

Null hypothesis $H_0: \mu_d = 0$

Alternative hypothesis $H_1: \mu_d \neq 0$

Results: The results from the pretest (M= 9.49, SD = 2.6) and posttest (M = 10.92, SD = 2.4) MUST tests indicate that the game-based intervention resulted in a statistically significant improvement in the students' scores, $t(38) = 3.91$, $p < .001$, (see Table 4.8 & Table 4.9). The posttest had a higher overall mean than the pretest. Both pretest and posttest had similar variability, but the posttest was less variable than the pretest. This was also mentioned earlier while observing the descriptive statistics of the pretest and posttest data (see Table 4.4).

Considering all the above, it may be concluded that the game-based intervention significantly improved the marks of the students; we, therefore, reject the null hypothesis of no significant difference in mean and conclude that the intervention, in fact, resulted in a significant difference in the mean from the pretest to posttest.

	Mean	**Std. Deviation**
Pretest	9.49	2.644
Posttest	10.92	2.421

Table 4. 8 Paired sample statistics

	Paired Differences				
	95% CI of the Differences				**Significance**
	Mean	Std.Deviation	t	df	Two-sided p
Pretest-posttest	-1.436	2.292	-3.913	38	<.001

Table 4. 9 Paired sample t-test results

<u>Step 3</u>

4.3.1.12 Analysis of Variance of Intervention Cohorts

The final grades of the students of the three courses in the intervention were obtained and compared. The means of the three groups were (71.42, 66.87, 69.50) and their variability was (15.19, 14.40, 10.97), respectively (see Table 4.10). An ANOVA test was conducted in SPSS to determine whether the courses had means that statistically significantly differed from each other. If the means do not differ significantly, then merging the data set to use as one group for comparison purposes may be justifiable.

Course Name	N	Mean	Standard Deviation
CHE 111-1	12	71.42	15.19
CHE 111-2	15	66.87	14.40
CHE 112	16	69.50	10.97
Total	43	69.12	13.26

Table 4. 10 Descriptive statistics for the three classes

	df	F	Sig.
Between Groups	2	.391	.679
Within Groups	40		
Total	42		

Table 4. 11 ANOVA of test scores for the three classes

Results: The 12 participants in CHE 111-1 had an average score of 71.42 (SD = 15.19); the 15 participants in CHE 111-2 had an average score of 66.87 (SD = 14.39); and the 16 participants in CHE 112 had an average score of 69.50 (SD =10.97), (see Table 4.10). The students' test scores do not differ significantly, $F(2, 40) = 0.39$, $p = 0.679$, (see Table 4.11). Further, the multiple comparisons table was observed to see how the students' scores compared to each other on a one-to-one basis. In all instances, all p-values were greater than 0.05, indicating that the results were not statistically significant. The decision was then taken to merge the three data sets for analysis.

4.3.1.13 Descriptive Statistics and Analysis of Variance of Previous Cohorts and Intervention Cohort

The grades of three previous cohorts of students studying the same courses and taught by the same teacher (and modality) as the students in the intervention cohorts were obtained. These grades were then compared with the grades of the merged intervention cohorts. Previous years of 2020 and 2021 were excluded from the data obtained due to the COVID-19 pandemic, and an online modality was employed either halfway through the semester (at the beginning of 2020) or for the entire semester (2021).

The students' final scores in the courses from previous cohorts (cohort 2018, 2019, 2022) were compared with the final scores of the students in the intervention cohort (cohort 2023). All four groups had means that were close in value to each other (75.43, 69.67, 67.52, 69,12), (see Table 4.12). There is a decrease in the mean from 2018 to 2019, then a decrease from 2019 to 2022, and then an increase from 2022 to 2023-intervention year, (see Table 4.12 and Figure 4.13).

Cohort Year	**N**	**Mean**	**Standard Deviation**
Cohort 1 2018	23	75.43	12.827
Cohort 2 2019	27	69.67	16.583
Cohort 3 2022	31	67.52	18.527
Cohort 4 2023	43	69.12	13.263
Total	124	70.01	15.451

Table 4. 12 Descriptive statistics of the final scores of 4 cohorts

	df	F	Sig.
Between Groups	3	1.275	.286
Within Groups	120		
Total	123		

Table 4. 13 ANOVA of the 4 cohorts

Multiple Comparisons		
Cohorts	**Cohort comparison**	**Sig.**
Cohort 1 2018	Cohort 2 2019	.552
	Cohort 3 2022	.247
	Cohort 4 2023	.389
Cohort 2 2019	Cohort 1 2018	.552
	Cohort 3 2022	.952
	Cohort 4 2023	.999
Cohort 3 2022	Cohort 1 2018	.247
	Cohort 2 2019	.952
	Cohort 4 2023	.971
Cohort 4 2023	Cohort 1 2018	.389
	Cohort 2 2019	.999
	Cohort 3 2022	.971

Table 4. 14 Multiple comparisons table of the 4 cohorts

Results: An ANOVA test was conducted in SPSS to determine whether the courses had means that statistically significantly differed from each other. The 23 participants in Cohort 1 (2018) had an average course grade of 75.43 (SD = 12.83); the 27 participants in Cohort 2 (2019) had an average course of 69.67 (SD = 16.58); the 31 participants in Cohort 3 (2022) had an average course of 67.52 (SD =18.53); and the 43 participants in Cohort 4 (2023) had an average course of 69.12 (SD =13.26). The students' final grades do not differ significantly from each other, $F(3,120) = 1.28$, $p = 0.286$ (see Table 4.12 & see Table 4.13). One-to-one comparison of significance values also suggests that there is no statistically significant difference between the means of the groups (see Table 4.14). This means that the students in the intervention group did not perform worse than the students in the previous cohorts, but rather, their performance was comparable to the previous years.

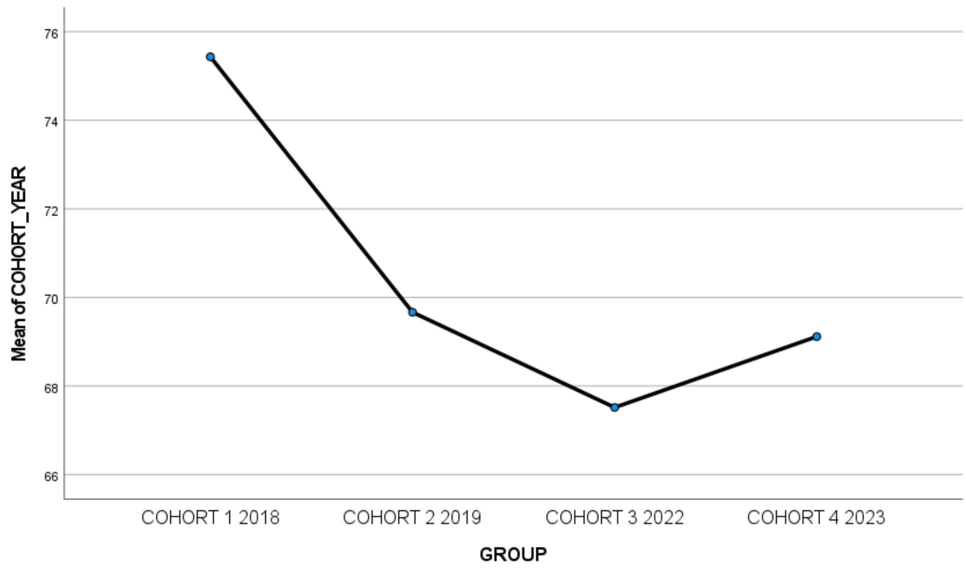

Figure 4. 13 Line graph comparison of the means of the 4 cohorts

Step 4

4.3.1.14 Summary of the Findings (RQ 1)

Considering steps 1 to 3 above, it may be concluded that the intervention had a positive impact on students' scores. The overall mean from pretest to posttest was higher and statistically significant. There was no statistically significant difference between the mean scores of students of previous cohorts and the intervention cohort; this means that the students did not do worse because of the intervention, but maintained a similar level of performance as the students in previous cohorts. In fact, there was an increase in the mean from 67.52 (2022) to 69.12 (2023), but this increase was not statistically significant, (see Table 4.12 & 4.14).

4.3.2 Answering Research Question 2

RQ 2: What are students' perceived competence, relatedness, and autonomy when game-based learning is used in their classroom?

I answer RQ 2 by looking at the results from the analysis of the Likert questions related to the self-determination theory (SDT). I examine the different elements of SDT separately, that is, competence, relatedness, and autonomy, and then make a conclusion. The students were asked this: *"Think about your experience of playing the algebra mathematics games. Please answer the following questions."* There was a total of 17 questions: six related to competence, five related to relatedness, and six related to autonomy. All questions were on a 5-point Likert scale ranging from strongly disagree to strongly agree.

4.3.2.1 Competence

A total of 37 students responded to questions 1 to 4 and question 6, while 36 students responded to question 5. Overall, the mean rating for the six questions in the competence element of the SDT on the 5-point Likert scale is between 3.86 and 4.05. These high ratings for the means suggest that the students felt competent during their experience of the game-based intervention. The highest mean rating was given to the question of whether students thought they became better at playing the mathematics games as time went by. This high mean rating suggests that students felt that the intervention caused them to improve their mathematics skills (for example, speed and accuracy) over time. The overall values for standard deviation were between 0.59 and 0.86. These low values for standard deviation suggest a low variability in student responses, indicating more agreement among the participants, (see Table 4.15).

	Questions	**Mean**	**Std Deviation**
1	With time, I became better at playing the mathematics games.	4.05	0.70
2	My math (game playing) abilities have improved since the beginning.	3.97	0.59
3	My mastery of the mathematics games improved with practice.	3.95	0.66
4	I was good at playing the games.	3.97	0.75
5	I felt competent at playing the games.	3.86	0.82
6	I felt capable and effective when playing the games.	3.89	0.86

Table 4. 15 Mean and standard deviation of the participants' Likert responses (competence)

Most of the respondents agreed that with time they improved their mathematics skills (84%). Thirty-two (87%) of the respondents felt that their mathematics improved since they started playing the mathematics games. Thirty (81%) of respondents felt that their mastery improved with practice, and they were good at playing the games. When asked whether they felt competent playing the games, 25 (70%) of the students reported feeling competent. Twenty-eight (76%) of the respondents felt capable and efficient when playing the games, (see Table 4.16 and Figure 4.14).

	Questions	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
1	With time, I became better at playing the mathematics games.	0.00% (0)	2.70% (1)	13.51% (5)	59.46% (22)	24.32% (9)
2	My math (game playing) abilities have improved since the beginning.	0.00% (0)	2.70% (1)	10.81% (4)	72.97% (27)	13.51% (5)
3	My mastery of the mathematics games improved with practice.	0.00% (0)	2.70% (1)	16.22% (6)	64.86% (24)	16.22% (6)
4	I was good at playing the games.	0.00% (0)	5.41% (2)	13.51% (5)	59.46% (22)	21.62% (8)
5	I felt competent at playing the games.	0.00% (0)	5.56% (2)	25.00% (9)	47.22% (17)	22.22% (8)
6	I felt capable and effective when playing the games.	2.70% (1)	2.70% (1)	18.92% (7)	54.05% (20)	21.62% (8)

Table 4. 16 Summary of Likert-scale response (competence)

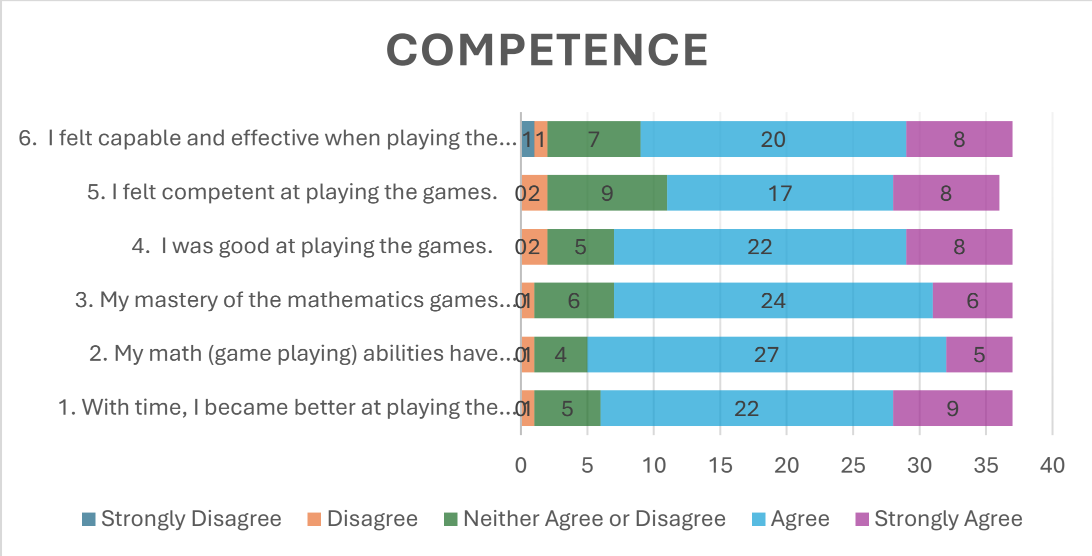

Figure 4. 14 Stacked chart of student responses to SDT questions (competence)

4.3.2.2 Relatedness

A total of 37 students responded to all five questions related to the relatedness element of the SDT. The overall mean rating for the five questions asked in this section is between 3.14 and 4.16. These above-average values for the mean suggest that students felt a sense of relatedness because they were playing the games in the game-based intervention. The standard deviation values ranged from 0.59 to 1.12. The highest mean ratings and lowest standard deviation were given for the questions asking respondents whether they really liked the people they played with and whether other players were friendly to them. The responses regarding whether students felt other players impacted their actions had a lower mean and higher variability, (see Table 4.17).

	Questions	**Mean**	**Std Deviation**
1	I really like the people I play with.	4.16	0.59
2	Other players are friendly towards me.	4.14	0.70
3	What other players did in the game had an impact on my actions.	3.32	1.12
4	I had to adapt my actions to other players' actions.	3.41	1.05
5	I was paying attention to other players' actions.	3.14	1.09

Table 4. 17 Mean and standard deviation of participants' Likert response (relatedness)

Thirty-three (89%) respondents really liked the people they played with. The remaining four (11%) were neutral. Thirty-five (95%) of the respondents thought that other players were friendly towards them. Ten (27%) of the respondents did not think what other players did in the game had an impact on their actions, while 19 (51%) of them thought other players' actions impacted them, and the remaining eight (22%) were neutral. Twenty (54%) of the respondents thought they had to adapt their actions to other players' actions, and 16 (43%) of the respondents reported that they were paying attention to other players' actions (see Table 4.18 and Figure 4.15).

	Questions	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	I really like the people I play with.	0.00% (0)	0.00% (0)	10.81% (4)	62.16% (23)	27.03% (10)
2	Other players are friendly towards me.	2.70% (1)	0.00% (0)	2.70% (1)	70.27% (26)	24.32% (9)
3	What other players did in the game had an impact on my actions.	5.41% (2)	21.62% (8)	21.62% (8)	37.84% (14)	13.51% (5)
4	I had to adapt my actions to other players' actions.	2.70% (1)	21.62% (8)	21.62% (8)	40.54% (15)	13.51% (5)
5	I was paying attention to other players' actions.	8.11% (3)	21.62% (8)	27.03% (10)	35.14% (13)	8.11% (3)

Table 4. 18 Summary of Likert-scale responses (relatedness)

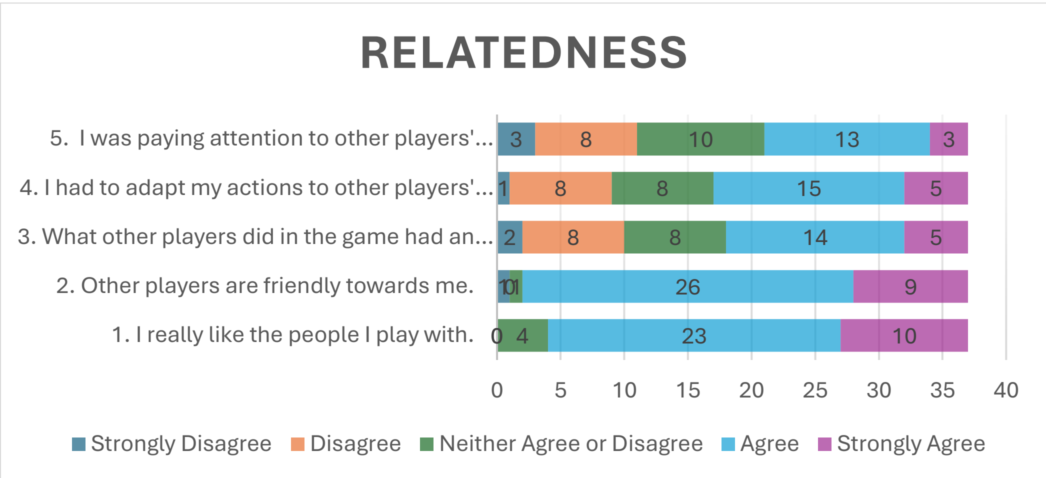

Figure 4. 15 Stacked chart of student responses to SDT questions (relatedness)

4.3.2.3 Autonomy

A total of 38 students responded to all six questions related to the autonomy element of the SDT. The overall mean rating for the five questions asked in this section is between 3.42 and 3.95. This is an above-average rating for the mean. This suggests that, overall, students felt a sense of autonomy during the game-based intervention. The standard deviation values were between 0.69 and 1.02. This means that the variability was not high across the board, and it suggests more agreement among the students, (see Table 4.19).

	Questions	**Mean**	**Std Deviation**
1	I was free to decide how I wanted to play the games.	3.50	0.91
2	I could approach the games in my own way.	3.76	0.90
3	The games allowed me to play how I wanted to.	3.55	0.91
4	I had important decisions to make while playing.	3.42	1.02
5	The choices I made during gameplay influenced what happened.	3.95	0.72
6	My actions had an impact on the games.	3.95	0.69

Table 4. 19 Mean and standard deviation of participants' Likert response (autonomy)

For all the questions relating to autonomy, most of the respondents reported between 47% and 82% agreement with the autonomy questions. Nineteen (55%) of the respondents felt that they were free to decide how they wanted to play, and 28 (74%) of them thought they could approach the games in their own way. Most of the respondents (68%) felt that the games allowed them to play how they wanted to play, (see Table 4.20 and Figure 2.16).

	Questions	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	I was free to decide how I wanted to play the games.	2.63% (1)	10.53% (4)	31.58% (12)	44.74% (17)	10.53% (4)
2	I could approach the games in my own way.	2.63% (1)	7.89% (3)	15.79% (6)	57.89% (22)	15.79% (6)
3	The games allowed me to play how I wanted to.	2.63% (1)	7.89% (3)	34.21% (13)	42.11% (16)	13.16% (5)
4	I had important decisions to make while playing.	5.26% (2)	13.16% (5)	26.32% (10)	44.74% (17)	10.53% (4)
5	The choices I made during gameplay influenced what happened.	0.00% (0)	5.26% (2)	13.16% (5)	63.16% (24)	18.42% (7)
6	My actions had an impact on the games.	0.00% (0)	2.63% (1)	18.42% (7)	60.53% (23)	18.42% (7)

Table 4. 20 Summary of Likert-scale response (autonomy)

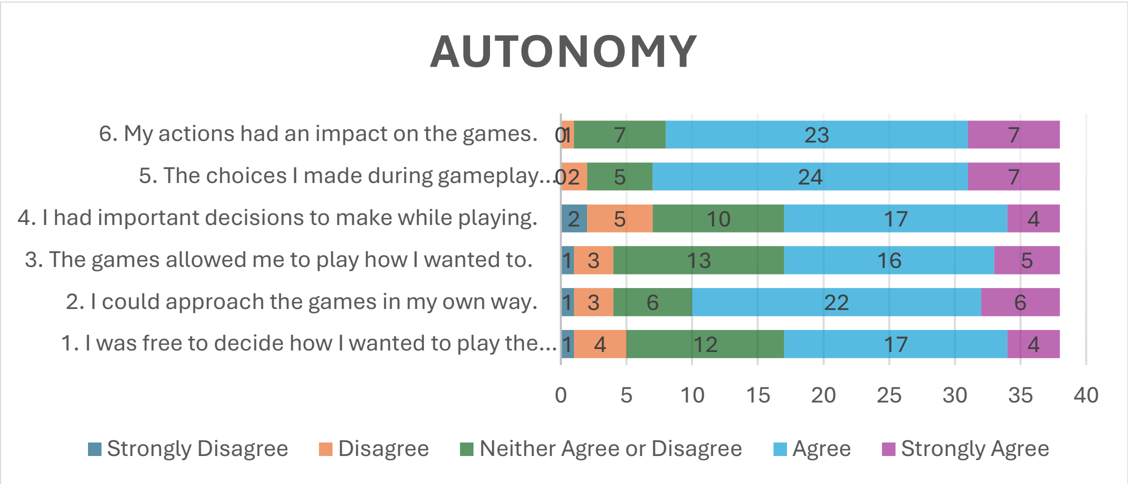

Figure 4. 16 Stacked chart of student responses to SDT questions (autonomy)

4.3.2.4 Summary of the Findings (RQ 2)

The elements of self-determination theory, competence, relatedness, and autonomy all had above-average mean ratings on the 5-point Likert scale. The variability ratings for the questions were also low indicative of student agreement to the questions asked. Taking all of the above into consideration, it may be concluded that students perceived feeling competence, relatedness, and autonomy because of their experience of the game-based intervention.

4.3.3 Answering Research Question 3

RQ 3: What are students' learning experiences of flow?

I will answer RQ 3 by looking at the results from the analysis of the Likert-type questions related to the flow scale. The students were asked this: *"Think about your experience of playing the algebra mathematics games. Please answer the following questions."* There was a total of 12 questions, and all questions were on a 5-point Likert scale ranging from strongly disagree to strongly agree. There were 38 responses to this question. The values for the mean ratings ranged from 2.24 to 4.34. The lowest mean rating (2.24) was in response to this: "During gameplay, I became completely lost in thought to the point where I was unaware of myself." All the other mean ratings were between 3.26 and 4.34. The two questions with the highest mean ratings are "I enjoyed learning mathematics by playing games" (4.34) and "The games were interesting" (4.32). The overall high ratings to the flow questions indicate a positive response in relation to students' perception of the feeling of flow during gameplay. The values for the standard deviation ranged from 0.60 to 1.33. Overall, the variability was low, indicating agreement among the students, (see Table 4.21).

	Questions	Mean	Std Deviation
1	I felt challenged while playing the game.	3.58	0.85
2	My thoughts ran smoothly and fluently while playing the game.	3.39	0.96
3	I did not notice time passing while playing the game.	3.26	1.33
4	I had no problem concentrating while playing the game.	4.03	0.93
5	My mind was completely clear while playing the game.	3.39	1.11
6	I was totally immersed in gameplay.	3.82	0.82
7	Thoughts occurred automatically, inspired by what I was playing in the game.	3.82	0.60
8	I knew what I had to do each step of the way.	3.82	0.97
9	I gained a good understanding of the mathematics content the game tried to teach me.	4.11	0.64
10	During gameplay, I became completely lost in thought to the point where I was unaware of myself.	2.24	1.13
11	I enjoyed learning mathematics by playing games.	4.34	0.66
12	The games were interesting.	4.32	0.65

Table 4. 21 Mean and standard deviation of participants' Likert responses to the flow scale

The statements that had the highest percentage of agreement among participants are “I had no problem concentrating while playing the game” (82%), “I gained a good understanding of the mathematics content the game tried to teach me” (84%), “I enjoyed learning mathematics by playing games” (90%) and “The games were interesting” (90%). Only five (13%) of the students agreed with this statement: “During gameplay, I became completely lost in thought to the point where I was unaware of myself,” while 19 (50%) of them agreed to this: “I did not notice time passing while playing the game,” (see Table 4.22 and Figure 4.1.7).

	Questions	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	I felt challenged while playing the game.	0.00% (0)	13.16% (5)	26.32% (10)	50.00% (19)	10.53% (4)
2	My thoughts ran smoothly and fluently while playing the game.	2.63% (1)	18.42% (7)	23.68% (9)	47.37% (18)	7.89% (3)
3	I did not notice time passing while playing the game.	13.16% (5)	18.42% (7)	18.42% (7)	28.95% (11)	21.05% (8)
4	I had no problem concentrating while playing the game.	2.63% (1)	5.26% (2)	10.53% (4)	50.00% (19)	31.58% (12)
5	My mind was completely clear while playing the game.	2.63% (1)	23.68% (9)	23.68% (9)	31.58% (12)	18.42% (7)
6	I was totally immersed in gameplay.	0.00% (0)	7.89% (3)	21.05% (8)	52.63% (20)	18.42% (7)
7	Thoughts occurred automatically, inspired by what I was playing in the game.	0.00% (0)	0.00% (0)	28.95% (11)	60.53% (23)	10.53% (4)
8	I knew what I had to do each step of the way.	0.00% (0)	15.79% (6)	10.53% (4)	50.00% (19)	23.68% (9)
9	I gained a good understanding of the mathematics content the game tried to teach me.	0.00% (0)	0.00% (0)	15.79% (6)	57.89% (22)	26.32% (10)
10	During gameplay, I became completely lost in thought to the point where I was unaware of myself.	31.58% (12)	31.58% (12)	23.68% (9)	7.89% (3)	5.26% (2)
11	I enjoyed learning mathematics by playing games.	0.00% (0)	0.00% (0)	10.53% (4)	44.74% (17)	44.74% (17)
12	The games were interesting.	0.00% (0)	0.00% (0)	10.53% (4)	47.37% (18)	42.11% (16)

Table 4. 22 Summary of Likert-scale responses to the flow scale

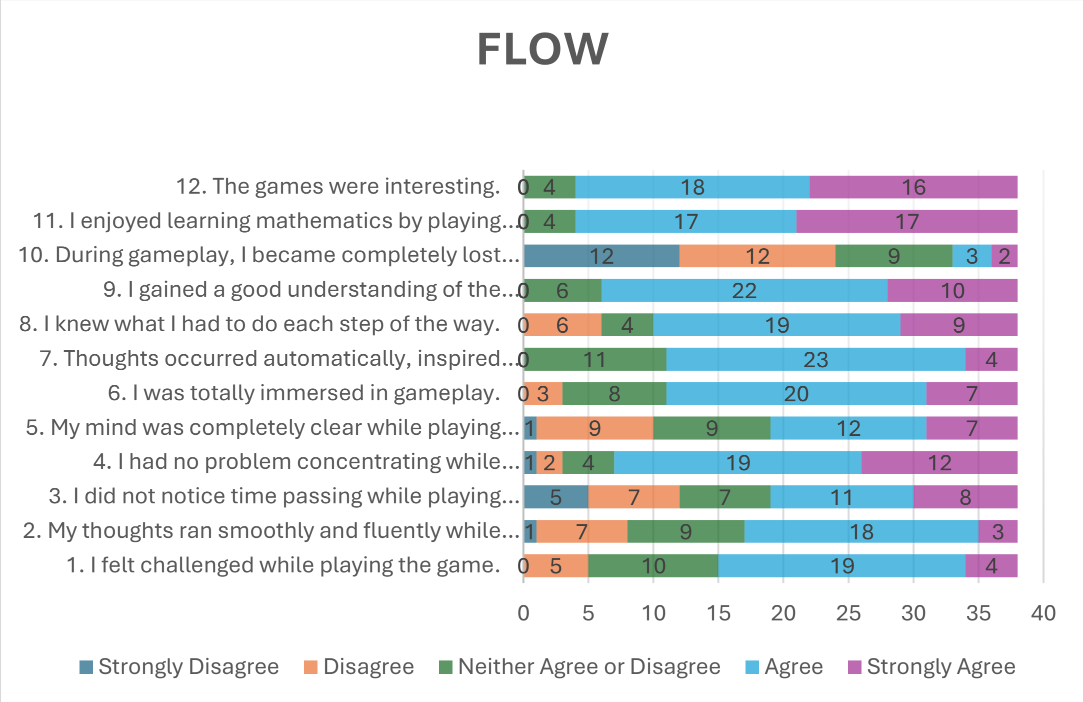

Figure 4. 17 Stacked chart of student responses to the flow scale questions

4.3.3.1 Summary of the Findings (RQ 3)

For the elements measuring flow, there was an overall positive result; however, most students did not agree that they were completely lost in thought to the point where they were unaware of themselves. On the other hand, many of them agreed to a high percentage, with some other elements of flow.

4.3.4 Answering Research Question 4

RQ4: What are students' perceptions of the benefits and challenges of mathematics GBL in their course?

To answer this research, a combination of Likert-type questions (focused on game elements), open-ended questions, and focus group interviews were analysed. First, I look at the results of the Likert-type questions, then the open-ended questions followed by the data obtained from the three focus groups.

4.3.4.1 Likert-type Game Element Questions

A total of 38 students responded to all seven questions related to whether they were motivated by game elements: points, leaderboard, competition, and instant feedback. The overall mean rating for the seven questions asked is between 3.79 and 4.21. This is an above-average rating for the mean. This suggests that, overall, students felt motivated by the game elements of points, leaderboard, competition, and instant feedback. The standard deviation values were between 0.84 and 1.13. This means that the variability was not high across the board, and it suggests more agreement among the students, (see Table 4.23).

	Questions	**Mean**	**Std Deviation**
1	The reward system of points and leaderboard motivated me to complete the tasks associated with the course.	3.95	1.10
2	The reward system of points and leaderboard motivated me to maintain a high level of performance.	3.92	1.13
3	The reward system of points and leaderboard motivated me to progress and get better.	3.92	1.06
4	I was motivated by the competitive element of leaderboards	4.05	0.94
5	I worked harder because I wanted to be at the top of the leaderboard.	3.79	1.06
6	Getting instant feedback was positive for my overall learning.	4.21	0.92
7	The reward system of points and leaderboard motivated me because I was working with others.	3.84	0.84

Table 4. 23 Mean and standard deviation of participants' game element responses

The percentage of overall agreement to the game element questions was remarkably high, ranging from 61% (23) agreement to 92% (35) agreement. Students overwhelmingly (92%) agreed with the statement, “Getting instant feedback was positive for my overall learning.” The other two statements with the highest percentage of agreement are “The reward system of points and leaderboard motivated me to maintain a high level of performance” (84%) and “The reward system of points and leaderboard motivated me to progress and get better” (79%), (see Table 4.24 and Figure 4.18).

	Questions	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	The reward system of points and leaderboard motivated me to complete the tasks associated with the course.	7.89% (3)	0.00% (0)	15.79% (6)	42.11% (16)	34.21% (13)
2	The reward system of points and leaderboard motivated me to maintain a high level of performance.	10.53% (4)	0.00% (0)	5.26% (2)	55.26% (21)	28.95% (11)
3	The reward system of points and leaderboard motivated me to progress and get better.	7.89% (3)	0.00% (0)	13.16% (5)	50.00% (19)	28.95% (11)
4	I was motivated by the competitive element of leaderboards.	2.63% (1)	2.63% (1)	18.42% (7)	39.47% (15)	36.84% (14)
5	I worked harder because I wanted to be at the top of the leaderboard.	2.63% (1)	7.89% (3)	28.95% (11)	28.95% (11)	31.58% (12)
6	Getting instant feedback was positive for my overall learning.	5.26% (2)	0.00% (0)	2.63% (1)	52.63% (20)	39.47% (15)
7	The reward system of points and leaderboard motivated me because I was working with others.	2.63% (1)	2.63% (1)	21.05% (8)	55.26% (21)	18.42% (7)

Table 4. 24 Summary of Likert-scale responses to the game element questions

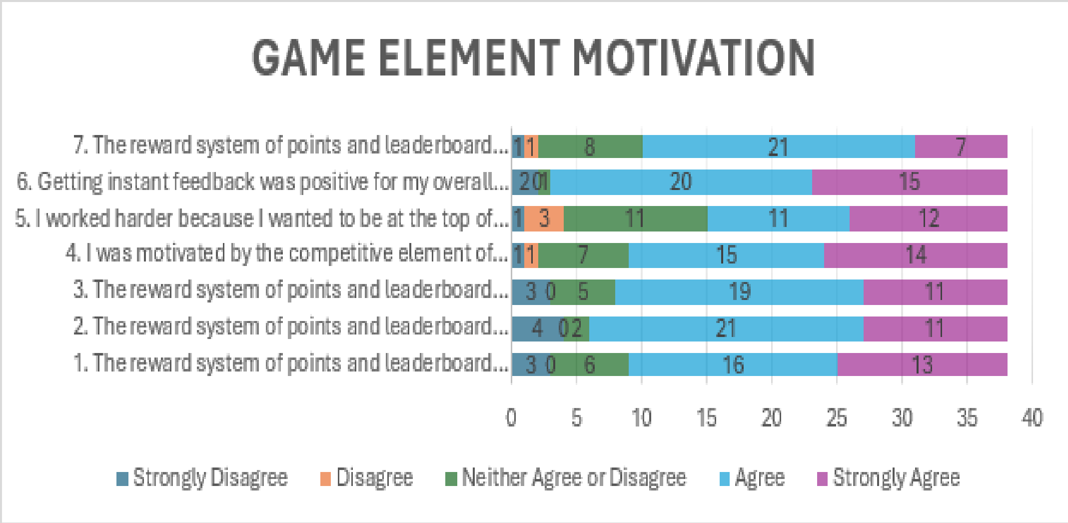

Figure 4. 18 Stacked chart of student responses to the game element questions

4.3.4.2 Open-ended Questionnaire Responses

There was a total of 43 recorded respondents from the Qualtrics output; however, only 37 of these respondents responded to survey questions. Ten of the 43 respondents visited the Qualtrics survey via the anonymous link provided, while the other thirty-three respondents visited via the QR code link provided. To explore research question 4, five open-ended questions (Q6, Q7, Q8, Q9, Q10), one Likert-type question, and three focus groups were used. In this section, I focus on the open-ended questions. The open-ended questions were analysed using reflexive thematic analysis (RTA). The six (6) phases of the reflexive thematic analysis are i) familiarisation with the data; ii) generating initial codes; iii) generating themes; iv) reviewing potential themes; v) defining and naming themes; vi) producing the report (Braun & Clarke, 2021).

4.3.4.3 RTA (An example)

For each question, I read the responses (open-ended questions and focus groups) of the students and made notes. The whole idea behind this was to familiarize myself with the responses given by the students. From the notes taken above, as well as the questionnaire data, I developed some initial codes and labeled them C1, C2, C3, and so on. I went through all responses again and made the codes based on every idea the students tried to convey. From the initial codes, I formed potential themes. In some instances, several codes were categorized under one theme. For example, C13 was "Games made Maths interesting," and C20 was "Games kept student interested"; they were both merged into the potential theme "interest and appeal." I then reviewed all the potential themes and further compressed them (where necessary) into more precise themes. The themes generated in phase 3 were again reviewed, and final themes were contemplated. The final themes were then named, (see Table 4.25).

Q6- Did you enjoy using games to learn mathematics? If yes, what made it enjoyable?	Q7- Are there any benefits to using games to learn mathematics? What are they?	Q8- Are there any challenges to using games to learn mathematics? What are they?	Q9- Would you recommend that math games be included in math/chemistry lessons? Why or why not?
Competition **Learning and comprehension** Improve competence **Scaffolding** Fun/Enjoyment **Fun Learning** Focus and Engagement **Interest and appeal** Shared experience **Peer interaction** Challenge **Interactive** Game/Game elements	**Fun learning** Non-traditional **Learning and comprehension** Improved mathematics skills **Improved speed** Time pressure benefits **Scaffolding** Focus and Engagement **Awareness of progress** Interest and appeal **Quick thinking/Cognitive** Enhanced confidence **Inclusive** Interactive	Peer pressure **Time pressure** Quick thinking required **Distraction** Embarrassment **Technical difficulties** Knowledge gaps/ No new knowledge **Thorough feedback necessary** Easy content	**Learning/improvement** Fun Learning **Enjoyment** Helpful **Motivation and engagement** Increased confidence **Non-traditional learning** Review tool/Starter **Stress Relief** Interdisciplinary benefits **Assessment/Feedback** Cognitive benefits **Applicability** Enhance understanding

Table 4. 25 Overview of open-ended questions themes

4.3.4.4 Overview of Feedback for Question 6

This question had 37 respondents. Thirty-six (97%) of the respondents said they enjoyed using games to learn mathematics. The responses to this question were overwhelmingly positive. One student responded "not really" when asked if he/she enjoyed using games to learn mathematics. The most prominent themes emerging from the analysis of the responses to question 6 were competition, competence (learning), and engagement (peer interaction). Many of the students emphasised those themes as their reason for enjoying using games to learn mathematics.

4.3.4.5 Summary of Student Responses to Question 6

Participants overwhelmingly stated that they enjoyed using games to learn mathematics. Many of them stated that using games to learn mathematics was fun. Most highlighted the competitive elements associated with the games as one of the reasons for their enjoyment. Some participants said the leaderboard and wanting to be on the podium were their reasons for enjoying the use of games in learning mathematics. Others indicated that the games allowed them to have fun and learn at the same time. Other participants stated that they enjoyed using games to learn mathematics because of the level of engagement and sustained focus that resulted from playing the games. They said that the games promoted enhanced understanding and learning. Some participants also enjoyed the social and peer interaction brought about when using game-based learning and even mentioned that having motivated team members made learning enjoyable; others enjoyed the challenge and interactive elements involved in the game-based activities. One student mentioned the fact that other students were open about admitting to making similar mistakes that he/she had made but were hesitant to admit them as a reason for enjoying game-based learning. Some participants found learning mathematics using games interesting. One participant said that using games to learn mathematics was enjoyable because it challenged his/her thinking, while another enjoyed using games to learn mathematics because of the teacher and the fact that games were used to facilitate learning. Examples of students' responses to question 6 are given below. The students were explaining why they enjoyed using games to learn mathematics. The responses are grouped according to the themes they were portraying, (see Table 4.26).

Themes	Supporting quotes
Competition	“The competition to see who did the best.” “Yes, it was the competitiveness of it all, it made it more interesting and kept me wanting more.” “The competitiveness made it enjoyable. My competitive side made me want to reach the podium.”
Learning and comprehension	“Yes, because I got a better understanding of transposing formulas.” “I got to learn new mathematics calculations and challenging myself to do the work was also fun.”
Improve competence	“Yes, improved my mathematics.”
Scaffolding	“It made the content easier to understand.”
Fun/Enjoyment	“It was fun.” “I enjoyed because the game was fun and competitive.”
Fun learning	“Yes. It was a fun way of learning.”
Focus and engagement	“I enjoyed it. I find it engaging and there wasn’t any point where I lost focus during the game.”
Interest and appeal	“Yes. Young adolescents tend to want to learn what they find interesting, and this game made math interesting.” “Yes, it was fun to play the games it really kept me occupied and interested.”
Shared experience	“What made it enjoyable was how the people in my class would admit to doing simple mistakes that I have done as well but didn’t want to admit.” “Having motivated team members.”
Peer Interaction	“Yes, playing with friends.” “Yes, playing and competing with others.” “Yes, getting to interact with my classmates.”
Challenge	“Yes, because it was a competitive challenge.” “Yes, because it challenged my thinking”
Interactive	“It was interactive.”
Game/Game elements	“The ending to see who won.” “The games in general and the teacher as well.” “Structural framework of the game itself.”

Table 4. 26 Themes and evidence (Q6)

4.3.4.6 Overview of Feedback for Question 7

This question had 37 respondents. All 37 respondents said there were benefits to using games to learn mathematics. The predominant themes that emerged from the students' responses are fun learning, learning, improved math skills such as speed and accuracy as well as quick thinking.

4.3.4.7 Summary of Student Responses to Question 7

All the participants indicated that there were benefits to using games to learn mathematics. Many of them agreed that the game-based learning intervention facilitated a fun way to learn. Participants saw the timed exercises as a benefit since it increased their speed and accuracy of mathematics calculations. Some students mentioned that they improved their mathematics skills because of the intervention. Others stated that the game-based activities were immersive and engaging and made it easier for them to maintain focus. Many participants stated that the game-based activities enhanced their learning of mathematics and their thinking skills as the games encouraged them to think quickly and analyse questions faster. Participants reported that the games kept them interested and eager to play and learn. They expressed that the games provided them with a different way to learn and they mentioned that this change was good, and it made learning more enjoyable. Participants also noted an increase in confidence when playing the mathematics games. They also improved their accuracy and efficiency when answering mathematics questions. Participants stated that the game-based intervention was 'hands-on' and beneficial to the visual learner. Examples of students' responses to question 7 are given below. The students were explaining what they considered to be some of the benefits of game-based learning. The responses are grouped according to the themes they portray, (see Table 4.27).

Themes	**Supporting quotes**
Fun learning	"Games open a fun perspective in Mathematics, and I think it allows us to learn better." "Make learning more enjoyable." "A fun and more interesting way of learning."
Non-traditional	"Yea there are, because there a different approach to what is usually used in a classroom, the change is good and makes learning more enjoyable." "Yes, being able to have fun will learning something new in a different way."
Learning and comprehension	"Yes, it will help you with working out questions." "They help me understand math problems more and become more efficient at answering them."
Improve maths skills	"Yes, there are benefits. Math skills are enhanced in a fun way." "Improvement of my maths skill." "Yes, improved math skills."
Improve speed	"Yes, such as helping to increase your pace when working out math calculations." "Yes, I learnt to do maths quicker." "Yes, you become faster at being able to work out problems."
Time pressure benefits	"Using games to learn mathematics under a set time influences your skills to learn simple math tricks that you wouldn't forget." "The speed of the game calls for effective production on the side of the players."
Scaffolding	"Yea, they teach you how to solve questions in an easy way that may seem harder."
Focus and engagement	"It's engaging, easy to stay focused without any effort."
Awareness of progress	"To see my self-progress."
Interest and appeal	"I feel like it could be used to keep people interested." "The game also keeps the youths' interest and makes them want to play, want to learn." "It's makes learning math more fun and want to learn more."

Themes	Supporting quotes
Quick thinking/cognitive	“Quick thinking without calculator to get a rough estimate.” “They make you think faster and analyzing questions quicker.” “Helps with cognitive skills.”
Enhanced Confidence	“More confident when playing math-based games.”
Inclusive	“Helps people who learn visually and hands on.”
Interactive	“Games are more immersive and fun.”

Table 4. 27 Themes and evidence (Q7)

4.3.4.8 Overview of Feedback for Question 8

There were 34 respondents to this question. Of the 34 respondents, 19 (56%) did not think there were any challenges with using games to learn mathematics. The remaining 15 (44%) mentioned some challenges, which are summarized below.

4.3.4.9 Summary of Student Responses to Question 8

One student felt discouraged by their classmates while using games in the classroom, but they did not elaborate as to what caused him/her to be discouraged. A few students commented on the timing element of the game-based learning; some reported feeling rushed to complete the task because of the time element associated with each question. One student said the timing element caused them to make mistakes they would not make under different circumstances. One student mentioned that students can get distracted from the main purpose of game-based learning. Another student reported that he/she was embarrassed because of not making it on the leaderboard. One student saw the lack of extensive feedback after each question as a challenge. Others mentioned technical difficulties associated with facilitating the game-based exercise in the classroom. Finally, one student stated that he/she did not find the games to be a tool for new knowledge but more a reinforcement tool.

Examples of students' responses to question 8 are given below. The students were explaining what they considered to be some of the challenges of game-based learning. The responses are grouped according to themes they were portraying, (see Table 4.28).

Themes	**Supporting quotes**
Peer Pressure	"Can feel discouraged by your classmates."
Time Pressure	"Since the exercise was timed, I felt rushed to complete the questions as fast as I could. Which led me to make mistakes I wouldn't usually make." "Answering the questions as fast as possible."
Quick thinking required	"Well, it depends on how fast you have to think because with the Kahoot games you had to think with speed and not everyone is fast thinkers." "It requires on the spot thinking."
Distraction	"People can get distracted by the main point of the game base learning."
Embarrassment	"There aren't really except for the fact that some people could be embarrassed not shown on the leader board and there are no explanations to the answers."
Technical difficulties	"Only technical difficulties."
Knowledge gaps/no new knowledge	"Yes. If you don't know the material beforehand then it's not helpful, but it is a great refresher, not for learning."
Thorough feedback necessary	"As long as concepts and equations are explained after the game, I don't see any challenging issues surrounding the games."
Easy content	"Yes, some questions are easy and attempting it without a calculator."

Table 4. 28 Themes and evidence (Q8)

4.3.4.10 Overview of Feedback for Question 9

There were 36 responses to this question. All 36 (100%) respondents said they would recommend the use of math games to be included in math/chemistry lessons. Thirty (81%) of these respondents gave a reason for their answer.

4.3.4.11 Summary of Student Responses to Question 9

Students saw mathematics games as helpful as they facilitated a fun way to improve mathematics skills in a way that is different from the traditional lecture. They reported that the mathematics games helped with the learning and understanding of mathematics while providing an interesting learning experience.

Students thought that math games made learning easier and the games function as a good motivation tool and confidence builder that helps them improve their performance.

Other students mentioned that the games help them to think, practice calculations, learn simple mathematics tricks, and help them to work more efficiently. Some students thought that games should be included in lessons because the competitive elements made the lessons enjoyable. A student expressed that the games assess learning and give instant feedback so you can assess your understanding. Students mentioned that mathematics games should be included in their lessons because there is a mathematics component in chemistry, and the games aid in chemistry comprehension when the mathematics is understood. Students said the games encourage them to attend classes, engage, and reduce stress levels when doing calculations. One student reported that the math games function as a good refresher of basic mathematics, and another said that their inclusion in lessons should be used to grab students' attention but not as the main method of teaching. Examples of students' responses to question 9 are given below. The students were asked why they recommended mathematics games be included in chemistry lessons. The responses will be grouped according to themes they were portraying, (see Table 4.29).

Themes	**Supporting quotes**
Learning/Improvement	"I would because it helps to learn maths." "Yes. Helps to improve performance." "Yes, because it is an efficient way of improvement."
Fun learning	"Yes, because they are a fun way to improve mathematical skills." "I would recommend it because it was an interesting learning experience for me, not only have I learnt to work more efficiently but I've also had fun competing with others." "Yes, I would recommend, it makes math fun."
Enjoyment	"I would, it was plenty of fun." "Yes, it's fun and easy."
Helpful	"Yes, because it was very helpful." "It helps." "It helps to keep the mind going."
Motivation and engagement	"Yes, because that is a good way to keep us motivated in class." "Yes. The games motivate students to come to class, to participate, and to learn." "Yes, they make me want to participate more."
Increase Confidence	"Yes, it helped me gain confidence in my math skills." "It will make you more confident when having math-based questions to do."
Non-traditional	"Yes, it can give student a little break from their actual lecture while still learning." "Yes, it provides a different learning environment."
Review/Starter Tool	"Yes, I would just because it's good practice for those who may need it." "I think it could be incorporated in math/chemistry as an attention grabber but not as a main method of teaching." "Yes. It is a good refresher for basic math."
Stress relief	"Yes, it helps reduce the level of stress when facing calculations."
Interdisciplinary Benefits	"Yes, because chemistry has an aspect of math necessary in solving equations." "Yes, they help in your chemistry comprehension because it relates a lot to math."
Assessment/feedback	"Yes, it makes learning fun, and it helps you to learn more as it tests you to see what you've learn."

Themes	Supporting quotes
Cognitive benefits	"Yes, helps with thinking."
Applicable	"Yes, because you can be able to apply the same knowledge when working out questions."
Enhance understanding	"Yes, because they help provide more understanding."

Table 4. 29 Themes and evidence (Q9)

4.3.4.12 Overview of Feedback for Question 10

There were 28 responses to this question. Twenty-four (86%) of these respondents did not have any other comments. Four respondents gave additional comments. Students thought that Game-based learning was helpful and enjoyable and should be added to all courses.

4.3.4.13 Focus Group Analysis Process

Three focus groups were conducted at the end of the semester after the game-based intervention, and questionnaire data were collected. A total of 32 students participated in the three focus groups. Figure 4.2 shows the breakdown of the focus group and the corresponding number of student participants. The focus group data was recorded and transcribed. The transcriptions were reviewed and organised as a first stage of analysis. The organisation involved highlighting questions and answers from all three transcriptions. This represented the first phase of the RTA, familiarization with the data. The highlighted data was then segmented into initial codes. All three transcriptions were coded together as one document. The steps of the RTA followed while analysing the questionnaires above were repeated for the focus group analysis.

These are the questions that the students were asked (see Appendix B):

1. How did the game-based intervention impact your abilities in the chemistry course?
2. What were some of the challenges that you had with the game-based intervention?
3. Did you get a good understanding of the mathematics that the games were trying to teach you?
4. Are there any benefits in your opinion to using games to learn mathematics?

The themes emerging from the analysis of the focus group data are summarised below under various headings.

4.3.4.14 Overview of the Themes Emerging from the Focus Group Questions

Many students reported several benefits to the game-based intervention. Some of the benefits the students mentioned in the focus group also came out in the questionnaire (see Appendix A). The focus group allowed the students to expand on some of their prior questionnaire responses. A few challenges regarding the game-based intervention were reported. Many of the challenges were mentioned in the questionnaire and echoed here in the focus groups. Students articulated several recommendations in the focus group data. Many of these recommendations were also mentioned in the questionnaire data.

The benefits, challenges, and recommendations that emerged from the analysis of the focus group data are summarized and tabulated below in Table 4.30.

Benefits	Challenges	Recommendations
Motivation	Time pressure	**Improve game content**
Learning	**Lack of autonomy**	Detailed feedback
Entertainment	Game platform challenges	**Game platform improvements**
Relationship building and teamwork	**Peer pressure**	School-wide GBL
Improve retention	Disability	**Different game platform**
Improve mental calculation	**Miscommunication**	Video questions
Accessibility	Human error	**Group and discussion**
Build confidence		
Review and reinforcement		
Familiarity		
Focus and engagement		
Increase math skills		
Competition		
Instant feedback autonomy		
Integration		
Hands-on		
Interactive		
Eager for class		
Self-evaluation		

Table 4. 30 Overview of focus group themes

4.3.4.15 Focus Group Summary – Benefits

The benefits that emerged from the analysis of the focus group data are summarized and tabulated below in Table 4.31.

Benefits - Summary of Students' Responses	
Motivation	▪ Digitalising the learning environment gave a different perspective and enhanced motivation. ▪ The games facilitated a non-traditional learning environment, this was different and attention-grabbing, resulting in the students being motivated. ▪ The games and competition motivated students, some of whom would have otherwise lost attention. ▪ Students who lacked focus in traditional lectures were engaged during game-based learning. ▪ Generally, students found learning through games motivating.
Learning	▪ Students learnt in the group setting (discussion/group game) because of mutual exchange with peers. They learnt from each other. ▪ Basic mathematics calculations became easier without the use of a calculator because of the game-based learning. ▪ Game-based learning facilitated a more efficient answering of questions. ▪ Game-based learning encouraged better understanding and made mathematics easier to learn. ▪ Students were able to apply their mathematics learning in their chemistry classroom. ▪ Due to game-based learning a student reported that he/she was finally able to understand a topic he/she previously found difficult. ▪ Students were able to calculate with ease because of the learning from the intervention.
Entertainment	▪ Students found the games exciting which made some more eager to do mathematics. ▪ A student who did not like mathematics previously reported being excited to do mathematics now because of the game-based learning. ▪ Students thought that game-based learning was a fun way to learn. ▪ Game based learning distracted students (in a positive way) from the fact that they were doing calculations due to the fun element associated with the games.
Relationship building and teamwork	▪ The group task fostered friendship like connections. ▪ The group setting facilitated collaboration and teamwork enabling students to share with and learn from each other. ▪ Students enjoyed the group games as they allowed interaction in smaller groups and some students that are usually uncomfortable speaking to the entire class, found the small groups better.

Benefits - Summary of Students' Responses	
	▪ Introverted students benefitted from group discussions within the group games as they were more focused.
Improve retention	▪ The games enabled students to retain the content more. ▪ One student who said he/she did not learn well in the traditional classroom due to getting distracted easily, became more focused while playing the games and reported that he/she will be better able to remember content from the games while doing an examination.
Improve mental calculation	▪ The games improved students' mental calculations without the need for a calculator. ▪ The game setting boosted students' skills at discerning the correct answer through mental elimination process.
Accessibility	▪ The games were accessible as the students all played on their cellphones.
Confidence building/empowerment	▪ The games allowed students to practice repeatedly which resulted in confidence building (with respect to the calculations). ▪ A student reported that the games boosted his/her confidence in answering questions and encouraged him/her not to second guess themself.
Review and reinforcement	▪ The game-based learning was seen as a good review tool that helps to reinforce basic mathematics.
Familiarity	▪ Students were familiar with and found playing the games easy as they all grew up playing computer games.
Focus and engagement	▪ The games were interactive and kept students focused. ▪ Some students were focused due to the competitive element associated with playing the games. ▪ Some students having short attention span and lacked focus in the traditional classroom were focused and engaged during game-based learning. ▪ The games encouraged students to participate more in class.

Benefits - Summary of Students' Responses	
Increase maths skills	▪ Students increased their mathematics skills such as speed, agility, and accuracy. ▪ They fostered the ability to think and calculate faster and to answer questions quickly. ▪ The time element was a driving force behind students' need for speed and some found that it made them faster at solving equations. ▪ Students learned new tricks that made them quicker with mathematics calculations. ▪ One student reported a boost in his/her skill of discerning the correct answer via the process of elimination due to playing the games.
Competition	▪ The competitive element associated with the games kept students focused and motivated. ▪ Overall, students enjoyed being involved in a competition.
Instant feedback	▪ Students reported that the instant feedback was a benefit to them.
Autonomy	▪ Students felt like they had control over the choices they made during gameplay. ▪ One student reported feeling the sense of autonomy initially, however time pressure and peer pressure impacted this as the student had to choose their answer quickly as everyone else had chosen theirs.
Integration	▪ Students were able to integrate the mathematics learnt from the game-based learning in their chemistry classroom. ▪ They reported that the games made understanding mathematics easier and in turn they were able to apply the mathematics to their chemistry and improve their chemistry. ▪ Students made the connection and saw the intersection between mathematics and chemistry.
Hands-on	▪ Students saw game-based learning as 'hands on' and saw this as a benefit to learning and receiving the information better.
Interactive	▪ The students reported that game-based learning was interactive, and they saw this as a benefit.
Eager /enthusiasm	▪ Some students looked forward to going to class and doing mathematics because of the game-based intervention.
Self-evaluation	▪ Playing the games helped students gauge their performance under pressure.

Table 4. 31 Table of summary of students' focus group responses- Benefits

4.3.4.16 Focus Group Summary – Challenges

The challenges that emerged from the analysis of the focus group data are summarized and tabulated below in Table 4.32.

Challenges - Summary of Students' Responses	
Time pressure	▪ Some students reported that they felt pressured to answer the questions quickly because of the timed task. However, students reported feeling more comfortable as they became more familiar and after a while it was no longer an issue for some. ▪ Students mentioned that the time constraints and speed pressure were a challenge. One student stated that it caused him/her to fumble and make mistakes. ▪ One student stated that the pressure to be on leaderboard under time constraints was a challenge. ▪ It was reported that longer questions needed more time than was allocated. ▪ One student mentioned that waiting on other students to finish before moving on to the next questions was not relaxing.
Lack of autonomy	▪ One student reported lack of sustained autonomy due to others calling out the answers and making other comments which influenced their answer choice. ▪ One student said that there was not much autonomy as there was one right answer that you needed to choose (Another student countered with the fact that some answers were close and you had to employ elimination to get the right answer, hence autonomy)
Game platform	▪ The Kahoot! character and avatar resets after phone sleeps temporarily and students must repeat process of creating character and avatar. ▪ Unfamiliarity with the platform at the beginning of the intervention. ▪ Students must keep looking up on the computer screen on the board to see the answer options and this was difficult for some.

Challenges - Summary of Students' Responses	
	▪ Questions were displayed on the classroom board and not on the students' device, this made it difficult to see and reduced the speed of answering questions. ▪ One student found the points and scoring methods of the Kahoot! games appeared unjustified. He/she reported that if you get one wrong answer, you will move several places down the leaderboard. He/She found this discouraging. ▪ Answers are automatically submitted after you click them and if you make a mistake, you cannot change.
Peer pressure	▪ Peer pressure from classmates to hurry up and choose your answer was seen as a challenge by some students.
Disability	▪ A student reported text size challenges because of his/her mild dyslexia. The student found it difficult to read the questions on the screen. ▪ A student reported that the numbers jumped around due to his/her dyslexia. This resulted in the student choosing the wrong answer.
Miscommunication	▪ One student did not like the group game due to miscommunication and distraction (from the task) within the group. This resulted in the team losing.
Human error	▪ Clicking the wrong answer by mistake has been highlighted as a challenge.

Table 4. 32 Table of summary of students' focus group responses – Challenges

4.3.4.17 Focus Group Summary - Student Recommendations

The recommendations that emerged from the analysis of the focus group data are summarized and tabulated below in Table 4.33.

Recommendations - Summary of Students' Responses	
Game content	▪ Games should include new knowledge. ▪ Games should have more content and questions. ▪ Game content level should be higher to intersect with the level of content that students are covering. ▪ Include more challenging questions. ▪ Include more chemistry questions (Some students disagree and think the mathematics alone is fine and they can 'combine' mathematics and chemistry later).
Feedback	▪ Provide more detailed feedback so that students can see what was done incorrectly.
Game platform improvement	▪ Put a ranking on every question so that students know where they are at for motivation purposes. ▪ Game delivery can improve.
Games-based learning in all classes	▪ Incorporate games in all classes using them as review and practice tools. ▪ Game based learning should continue throughout the school year.
Other game platform	▪ Using a different game platform than Kahoot! for example, Quizizz. (With Quizizz, you get the chance to correct your wrong answers. Another advantage is that the questions are timed, but you are not penalized for being slow. You can also move ahead without waiting for the other students to play. You see both the question and answer on the same screen (your device), so you do not have to look up on the board to see the question and then respond on your device.) ▪ Use a platform that does not wait for everyone to finish before moving on to the next question.
Video questions	▪ Include video questions, as this will foster better learning and recall. (Some students immediately disagreed with that recommendation, suggesting that it would be distracting and it would minimize engagement. They added that videos would take a longer time to process and comprehend).
Groups & Discussion	▪ Include discussion questions so that students can share their knowledge and others learn in the process. ▪ Do more group games (integrating discussion questions) to foster collaboration and learning.

Table 4. 33 Table of summary of students' focus group responses- Recommendations

4.4.4.18 Student Recommendation- Kahoot! Platform

Students reported that the Kahoot! platform was a good one to use in the game-based intervention. Some of the reasons given are that it was easy to learn the steps to join the game, it was easy to navigate after joining, the platform instructions were clear, and there were already existing games relevant to the course available on Kahoot!

4.3.4.19 Student Recommendation-Time Element

A few students highlighted the timed game task as a challenge as they felt pressured by it, and it sometimes led them to make the wrong choice. On the other hand, some students thought that the time element had a positive impact and that timing the game tasks was more of a benefit than a challenge. Some students argued that the timing would positively impact your speed even if you experience challenges in the beginning. Overall, some saw the timing element as a useful tool provided there was enough time allocated to do each question.

4.3.4.20 Summary of the Findings (RQ 4)

The students reported several benefits and challenges to game-based learning in the classroom, but overall, the results were positive in terms of the students' experience of the intervention in their classroom. The students also made some recommendations as to some changes to facilitate improvements when game-based learning is used in the future.

4.4 Concluding Remarks

In this chapter, I presented the data I collected using graphs and tables. I also provided an analysis of the data using descriptive statistics, t-tests, ANOVA, and reflexive thematic analysis. I gave summaries and overviews of the findings. I use the findings to provide a more in-depth explanation of the results and, hence, explicitly answer the research questions in the discussion chapter that will follow this one.

5 Discussion and Conclusion

5.1 Introduction

The inclusion of game-based learning in classroom teaching and learning has gained traction in recent years and has been advocated by many as a viable classroom pedagogy, capable of mitigating some classroom difficulties and enhancing student learning experience and outcomes (Juhari & Abu Bakar, 2020; Elsattar, 2018; Lee et al., 2023; Shabihi et al., 2016; Chen et al., 2022). Despite the recent prevalence of studies in the field, there is a gap in game-based learning (GBL) research in the Caribbean and limited studies relating to higher education mathematics. Concerning mathematics in the Caribbean region, innovative ways are needed to tackle the unsatisfactory level of performance of students exiting secondary schools and subsequently entering higher education. Many students have a general dislike for mathematics (Leacock, 2015) and, hence, are not motivated to learn it or engaged in the learning environment. Game-based learning may be the answer the Caribbean is looking for as it provides an innovative way to transform the mathematics classroom and improve students' learning outcomes and overall learning experience. GBL can promote fun learning so students can improve in competence while having fun and interacting with each other.

This study explored mathematics game-based learning to determine its viability in relation to its potential to enhance competence and impact student learning experience from the students' point of view.

In this chapter, I synthesize the findings obtained from my investigation of mathematics GBL in a higher education chemistry classroom. Using various research instruments, I explored students' academic performance, their perception of GBL through the lens of the self-determination theory (SDT) and flow theory, and their perceived benefits and challenges of the GBL intervention. The students' scores, focus group, and questionnaire examined the students' learning experience using different instruments, but the findings are interrelated and this will be shown in the body of this chapter.

This chapter expounds on the results and findings of the preceding chapter, makes comparisons to existing literature, explores the significance and implications of the research findings, and proposes future research directions while considering the limitations faced in the study. Finally, the discussion aims to suggest pragmatic and replicable insights (to stakeholders) capable of informing mathematics teaching and learning practices at the higher education level.

5.2 Summary of Key Findings

This section provides a summary of the key findings obtained from the analysis of the data of the game-based intervention. The findings relating to the investigation of students' academic performance revealed a statistically significant difference in means from the pretest to the posttest, $t(38) = 3.91$, $p < .001$. Additionally, though there was no significant difference between the mean score of students of previous cohorts and the intervention cohort, there was an increase in the mean score of their final grades from 2022 (previous cohort) to 2023 (intervention cohort). As a result, it was determined that the GBL intervention positively impacted students' grades (RQ 1).

The findings from the second research question suggest that some students perceived competence, relatedness, and autonomy during the GBL intervention. This aligns with the principles of the self-determination theory (RQ 2). SDT indicates that the satisfaction of the three psychological needs of autonomy, competence, and relatedness can enrich self-determined motivation, which is associated with well-being and student life satisfaction (Tu et al., 2024). Since the result of the GBL intervention suggests satisfaction of the three psychological needs, I conclude that the intervention was not detrimental to students but rather supported their well-being. Furthermore, satisfaction of autonomy, competence, and relatedness are also consequential in predicting well-being among higher education students with disabilities (Tu et al., 2024), and so, an initiative such as the GBL used in this study can facilitate a learning environment that is inclusive and accessible to students of various needs.

Regarding the students' perception of flow while playing the learning games, many of them did not achieve a flow state during the game-based intervention (RQ 3), according to the results. However, there was a compelling consensus that they enjoyed the intervention (97% of the students said they enjoyed using games to learn mathematics). Additionally, the students agreed to a high degree on most key flow elements, such as enjoyment, challenge, clear goal, and competence; however, only a few (5 out of 38) reported that they were completely lost in thought to the point that they were unaware of themselves. Apart from that one instance of non-alignment, most students agreed with the other flow components.

The experiences of flow have also been associated with well-being. More specifically, it has been documented in psychological research that individuals who have more frequent experiences of flow have higher life satisfaction, higher self-esteem, and more fulfilling experiences (Isham & Jackson, 2022). Isham and Jackson (2022) further expanded to say that while high-quality experiences of flow can result in instantaneous feelings of well-being at the time of the flow activity, more frequent flow experiences can result in greater well-being, even outside of the period of the flow activity. This is a very profound claim, and it could have far-reaching implications for sustained GBL applications to classroom environments that promote the flow experience, such as the GBL intervention in this study.

Enjoyment was one of the key flow elements that emerged from the questionnaire and focus group data. Activities that promote flow, including intellectually challenging ones, can be enjoyable and satisfying, encouraging creativity and feelings of accomplishment. Although these feelings may occur retrospectively, for the most part, the development of an individual’s talent and creativity is associated with those individuals who enjoy their chosen activity (Shernoff et al., 2003). Since students in this study associate a sense of enjoyment with playing mathematics games and, by extension, learning mathematics, this can have a meaningful impact on their attitude towards mathematics and their level of creativity when engaging in mathematics activities in the GBL-enhanced classroom.

Finally, students reported several benefits (for example, motivation, entertainment, learning, relatedness, competence, competition, instant feedback, and interaction) and challenges (for example, time pressure, peer pressure, human error, disability, technical difficulties, distraction) of GBL in the classroom (RQ 4). They also suggested some recommendations to improve future interventions (for example, include discussion questions so students can collaborate, use a different game platform that allows students to work at their own pace, and include GBL in all classes all year round).

5.3 Interpretation of Findings

In this section, I interpret the findings, compare and contrast them with the current GBL discourse, and explain them through the lens of the theoretical framework of flow and SDT. I discuss the findings in order of the research questions making links to the theoretical framework where applicable.

5.3.1 The Impact of Mathematics GBL on Students' Academic Performance

Research question 1 aimed to investigate GBL's impact on students' academic performance. This was investigated in two ways: Firstly, by comparing students' pretest and posttest scores and secondly, by observing their final course grade compared with that of the final course grades of students of three previous cohorts. These combined quantitative methods were considered sufficient to provide a valid and reliable answer to the research question. The first part of the analysis used a paired t-test to investigate students' performance in their pretest before the intervention compared to their posttest after the intervention. The t-test revealed that the difference in the pretest to posttest mean was statistically significant, $t(38) = 3.91$, $p < .001$. This finding suggests that it is unlikely that this difference in the mean is merely down to chance but rather because of the game-based intervention that took place between the pretest and posttest. These findings align closely with that of existing literature regarding the impact of mathematics game-based learning on students' academic performance. For example, Marie et al. (2020) and Delgado-Gómez et al. (2020) showed in their studies that mathematics GBL has a statistically significant impact on students' grades.

During the intervention, the students played mathematics games on Kahoot! that were specifically designed to review pertinent mathematics topics covered in the initial review and relevant to the mathematics needed for the chemistry course they were taking. The content of the games was also similar to the topics in the pretest and posttest. The Kahoot! games were used to review and reinforce fundamental mathematics concepts the students would need to apply to their chemistry computations during the semester.

One explanation for obtaining statistically significant results in the pretest to posttest could be that the students learnt from the Kahoot! games since they got a chance to repeat and review several lessons. As shown in Chapter 4, students were competitive and wanted to win the games, so they increased their speed and accuracy to meet the challenge. Students were enthusiastic about learning in a fun environment, making the learning interesting. Saha et al. (2024) reported that two factors of success in university mathematics were enthusiasm and interest in mathematics content. The statistically significant result obtained as a result of the GBL intervention is a demonstrated example of the students' success facilitated by their enthusiasm and interest in the mathematics content.

Another possible explanation for students' statistically significant results could be that the GBL environment was instrumental in supporting flow and SDT, enabling the students to have optimal psychological experiences and hence were able to do their best. The GBL environment, in its facilitation of flow and SDT, provided an enjoyable learning environment with healthy competition, feelings of camaraderie, confidence, new and improved skills, autonomy, and competence. These factors all contributed to the students feeling empowered in their learning environment and hence complemented their learning experience and overall well-being, setting the stage for them to perform at their best.

It is worth noting that a possible confounding variable that may have contributed to the students' improvement from the pretest to the posttest is that the initial review was given after the pretest, so the competence demonstrated from the pretest to the posttest could have been as a result of learning from the initial review. However, students agreed in the focus group and questionnaire that the GBL intervention increased their learning and comprehension. In any case, there was one initial review session and several GBL sessions, which are more likely the reason for the significant increase in means. Despite the initial review session having the potential to be a confounding variable, it was necessary to do it at the beginning of the intervention to make sure students knew what to do in the Kahoot! games, as the games would not otherwise work as a standalone in the context in which they were used, especially since this was an interdisciplinary classroom and mathematics was not the main focus.

The second part of the analysis used ANOVA to compare the students' final grades in the intervention cohort with those of students in three previous cohorts. These results revealed no significant difference in the means $F(3,120) = 1.28$, $p = 0.286$. However, the overall means were higher than the previous year and comparable to those of the three previous cohorts.

The conclusion from the quantitative and qualitative findings is that the GBL intervention resulted in learning (in an enjoyable learning environment) and provided a good foundation for the students to apply mathematics to their chemistry courses. One explanation for obtaining test score results that were not statistically significant despite the significant results in the pretest to posttest is that the mathematics review sessions did not cover the chemistry aspects of the student's course. So, while students understood the mathematics, their final grades were not only testing mathematics but also chemistry, which the review did not cover.

Another contributory factor may be the fact that the students' final grades were not only based on their final exam (which had elements of mathematics in chemistry), but it was a composite score of labs, coursework, and quizzes. These other elements of the final grade did not necessarily measure the learning from the GBL intervention. Upon reflection, looking at aspects of the students' final papers with mathematics applications related to what was reviewed in the GBL could have provided more information regarding their learning from the GBL intervention.

A final reason could be that the intervention lasted only a few weeks. It is possible that this was not enough time for students to assimilate and apply, so while mathematics learning occurred, they did not have enough time to integrate this into their chemistry.

Overall, the students' final grades were comparable to those of students of previous cohorts. This indicates that the students did not perform worse due to the GBL intervention, and therefore, this is a viable classroom technique that may be used to complement the teaching and learning process. Furthermore, the results from the pretest to the posttest indicate that it is possible to obtain statistically significant grades in a GBL environment and, therefore, show the satisfaction of the three basic psychological needs of competence.

5.3.2 Students' Perceived Competence, Relatedness, and Autonomy

Research question 2 explored the students' perceptions of the GBL intervention through the SDT lens. The three components of the SDT are competence, relatedness, and autonomy. Students' responses to a 5-point Likert agreement scale resulted in mean ratings that were above average in all three SDT areas. These ratings will now be discussed and corroborated with evidence from the open-ended questions and/or focus groups.

5.3.2.1 Competence

As demonstrated in the Likert responses in Chapter 4, most students felt competent during the GBL intervention and felt that their mathematics mastery improved with time and practice. These results further support the claim (above) that students' learning improved due to the game-based intervention. This result is not surprising for several reasons (listed below). Furthermore, students expressed in the questionnaire and focus group that they became more competent due to the GBL intervention; for example, when asked about their perceived benefit of the mathematics learning games, one student responded, "They help me understand math problems more and become more efficient at answering them." Another student explained, "Yes, there are benefits. Math skills are enhanced in a fun way." In addition to this, the literature agrees that competence can result from game elements in game-based learning (Lee et al., 2023). I discuss some of the ways that students could have fostered competence during the GBL intervention:

Repeated practice - The GBL intervention enhanced students' learning through repeated practice and interfacing with several game elements. Students played the games over several weeks, and this repeated review helped students enhance their accuracy and mastery of the content in the games. When asked whether they would recommend mathematics games to be included in math/chemistry lessons, one student responded, "Yes, I would, just because it's good practice for those who may need it."

Competition, leaderboard, and time pressure - Students were engaging with several game elements that could likely improve competence, such as competition, leaderboard, and time pressure. The findings illustrated in the previous chapter indicate that students were overwhelmingly competitive, and this could, in turn, enhance competence (Greipl et al., 2020). Students wanted to get on the leaderboard and were rewarded if they could give the correct answer in the shortest possible time, so some of them developed strategies to answer questions with speed and accuracy (as indicated in their questionnaire and focus group responses), improving their overall skills and competencies.

Instant feedback – Instant feedback can promote competence (Lee et al., 2023). Enhancing self-belief can motivate students to take charge of their learning, ultimately building confidence. When given instant feedback, students can see whether they are doing well or not. For those who are doing well, the feedback can validate and reinforce their confidence and competence. For the students who are not doing so well, feedback can negatively impact their competence, but on the other hand, it encourages them to persevere and build on their competence. Improving the students' competence can positively impact students' motivation, engagement, overall learning experience, and student well-being. As students become more competent, they feel more capable and are more motivated to engage.

5.3.2.2 Relatedness

Students reported feeling a sense of relatedness. Likert responses revealed that students liked the people they played with (33 out of 37) and felt other players were friendly to them (35 out of 37). Other aspects of relatedness were also echoed in the open-ended questionnaire and focus group. For example, the students were asked, “Did you enjoy using games to learn mathematics? If yes, what made it enjoyable?” One student responded, “Yes, getting to interact with my classmates.” Another student mentioned in the focus group that the group game aspect of the GBL activities facilitated collaboration and fostered friendship-like connections. This result is unsurprising as these students study as a small cohort, many of whom are friends and usually have multiple classes together. Though to a lesser percentage of agreement, students also felt that they were related to their classmates in other ways. They felt that what other players did in the game impacted their actions; they had to adapt their actions to the actions of other players, and they were paying attention to what the other players around them were doing. Other than the already established friendship dynamics, students could have fostered a feeling of relatedness during the GBL intervention in a number of ways; these are discussed below.

Peer interaction - Student relatedness was promoted by facilitating the GBL (see Table 4.31). The GBL-infused learning environment encouraged peer interaction. From my experience of playing Kahoot! in the classroom, students usually have friendly banter between questions. For example, they joke about each other's chosen name and avatar, support each other in accessing the games, or joke about how many people chose a wrong answer. The topics of the friendly banter vary, but it is usually friendly and likely to promote relatedness.

Group games - When students did the group games, this encouraged engagement and teamwork through discussion, further contributing to the feeling of togetherness. Some students, who are usually uncomfortable speaking to the entire class, found the small groups better. Additionally, introverted students benefitted from group discussions within the group games as they were more focused, according to the account given by the students in the qualitative findings.

Feedback and leaderboard - These elements can promote relatedness. For example, as stated above, students sometimes have jovial interactions between questions (from my experience). However, sometimes these interactions are specifically based on their leaderboard position and/or the feedback given. They may joke about who is on the leaderboard and how they can surpass each other. In that case, it can encourage a sense of relatedness, promoting friendship and classroom camaraderie.

5.3.2.3 Autonomy

The results from the Likert responses indicate that the students' autonomy was supported during the GBL intervention. However, the findings from the focus group are mixed; as a result, autonomy was reported as a benefit and a challenge. So even though some students felt autonomous, others felt their autonomy was curtailed or not sustained, according to the findings in the data analysis. Here are some of the ways that students could have fostered a feeling of autonomy during the GBL intervention:

Answer choices - Students could take control of their answer choices as they engaged on the Kahoot! platform. They got the opportunity to answer questions from the games on their own devices. This could have fostered a feeling of autonomy. Furthermore, it was expressed in the focus group that they felt they had control over their answer choices.

Instant feedback & challenge - Game elements such as instant feedback and challenges could have also contributed to students' autonomy. With instant feedback, students can make necessary skill adjustments to meet their respective challenges. This can give them the feeling of being in control of their learning (Lee et al., 2023).

Collaboration – The students indicated in the previous chapter that group games encouraged collaboration, which may have impacted autonomy as students are encouraged to take the initiative and communicate with their peers.

Competition and leaderboard – The elements of competition and leaderboard encouraged students to take control of their progress and learning. For example, if a student is not doing well on the leaderboard, they may take the necessary steps to improve their skills, whether during the existing game or afterward for a subsequent GBL session. Students indicated in the qualitative data that they came up with ways to improve their skills so they could do better.

Motivation and engagement – Game-based learning promoted motivation and engagement (see Table 4.28). Motivation can positively impact the students' autonomy as they feel more empowered to act and participate when motivated. Conversely, insufficient autonomy can negatively impact extrinsic motivation (Ryan & Deci, 2000). Further, self-determined extrinsic motivation is positively linked to the flow theory (Kowal & Fortier, 1999). The GBL activity may have promoted self-determined extrinsic motivation among the students.

5.3.2.4 Summary of the Self-determination Theory

The findings from the Likert scale data on the self-determination theory align closely with the themes found from the open-ended questions and focus group analysis. For example, relating to competence, students wrote that game-based learning helped them improve their mathematics, and they became more confident and competent (competence). Students also wrote that they enjoyed the intervention because it allowed them to play and compete with their peers (relatedness). Some students reported feeling autonomous. For example, one student stated that they initially felt a sense of autonomy. However, time and peer pressure caused them to lose that autonomy as they felt forced to respond to the question as everyone else had done. The comparison of Likert data and focus group and questionnaire data indicates that the data converges; this underpins the findings' reliability and validity and provides a panoptic view of GBL through the lens of SDT.

Self-determination theory proposes that humans experience higher psychological satisfaction when these three basic needs (autonomy, competence, and relatedness) are realized (Chiu, 2022; Tyack & Mekler, 2020; Grasse et al., 2022). Supporting the basic psychological needs of autonomy, competence, and relatedness can help people achieve optimal growth (Ryan & Deci, 2020). An alignment of the SDT elements can transform a previously extrinsically motivated person to a state that mirrors intrinsic motivation due to its autonomous and self-determined elements (Ryan & Deci, 2000). Despite these claims about the benefits of aligning with self-determination theory to fulfil basic psychological needs and hence benefit from motivation, engagement, and optimal growth, Farrell & Moffat (2014) designed a game with the principles of the SDT, and after testing and finding no correlation between SDT and engagement, concluded that SDT alone does not predict engagement. Conversely, Proulx and Romero (2016) reported enjoyment, motivation, and engagement from their SDT research.

According to the results of this study, the GBL intervention facilitated the satisfaction of the three basic psychological needs of the SDT. Students reported feeling motivated during the GBL activities. This motivation can empower them to engage and thus enhance the learning experience and environment. In addition to the findings above, students were directly asked whether some game elements motivated them. They reported that points and leaderboard motivated them to complete tasks, maintain high performance and progress, and improve. They also reported that they were motivated by the competitive element of the leaderboard and worked harder to get on it.

Despite the mixed results on autonomy obtained in the focus group, most students felt autonomous. This conclusion is supported by the Likert findings with an above-average mean for all the autonomy questions. The instance/s of compromised autonomy may have impacted students' overall motivation.

5.3.3 Students' Perceived Learning Experiences of Flow

Research question 3 explored the students' learning experience of flow using a 5-point Likert agreement scale. In all instances, an above-average mean was reported for all flow elements, except in one instance. Students felt challenged; they were focused and overlooked time passing during the GBL activity; they found the games immersive and did not have problems concentrating; they agreed that the games were interesting; they enjoyed playing them and gained a good understanding of the mathematics they tried to teach. These findings are also consistent with those in the focus group and open-ended questions. This emphasises the reliability of the results obtained. The elements or game themes that may have fostered flow will be given first, followed by those that may have hindered.

5.3.3.1 Fostering Flow in a GBL Environment

Challenge vs. skills balance– I created the questions that the students did on the Kahoot! games. They were carefully chosen to be at an appropriate challenge/skill level. Furthermore, students were given an initial mathematics review session, which set the foundation for the content of the games. In addition, students did not express frustration about the difficulty level of the questions compared to their skill, except for one comment that said the content was easy and another that said it was “fun and easy.” Of course, there may have been a few students who found the content too challenging and others who found it too easy, which could have negatively impacted flow. However, the Likert result suggests the students felt challenged while playing the game and had the necessary skills or the opportunity to enhance them, evidenced by their agreement with the question about their understanding of the content. When the balance of skill and challenge are in alignment, the environment becomes conducive to experience flow (Shernoff et al., 2003; Csikszentmihalyi,1975)

Immersive environment – The students were very engaged during the games and reported that they found the activities immersive. The literature states that immersion in a game activity has the potential to bring about flow (Almeida & Buzardy, 2019).

Social interaction – Peer interaction emerged as one of the prominent themes when the students were asked to explain why they enjoyed GBL. This helped them feel a sense of belonging, putting them at ease during the GBL activities. Enjoyment can facilitate flow (see below).

Enjoyment – Students reported (overwhelmingly) that the activities were fun and they enjoyed themselves. They appreciated the fact that the GBL activities transformed the classroom environment (Table 4.31). Overall, enjoyment was one of the most prominent themes that emerged from game-based intervention. Enjoyment is a key flow element (Shernoff et al., 2003; Hamari & Rowe, 2014) that also contributes to students well-being.

Interesting – The students found the games interesting. They reported that it was an interesting way to learn mathematics. Interest in an activity is also one of the key flow indicators (Shernoff et al., 2003; Hamari & Rowe, 2014)

Competence – Students develop their competence during the activities, which boosts their confidence and puts them at ease to continue engaging.

Instant Feedback – Instant feedback can give a feeling of continuity and enhance engagement. According to Zabala-Vargas et al. (2021), feedback gives the feeling of uninterrupted progression, encouraging players' engagement.

In summary, it is interesting that only 13% (5 out of 38) of the students agreed that they became completely lost in thought to the point where they were unaware of themselves. So, even though students agreed they were focused, they did not agree that the focus was so deep that it made them unaware of themselves. I propose the following as reasons the students did not agree to focus to the point of unawareness:

5.3.3.2 Potential Negative Impact on Flow

Peer pressure – Some students felt pressured in the GBL environment. One student explained that classmates can discourage you during the GBL activity. If you are preoccupied with negative emotions, such as feelings of discouragement, it is unlikely that you will achieve that deep level of focus in the GBL activity.

Time pressure – Students were making mistakes and rushing to answer questions due to time pressure. They required on-the-spot thinking. This can negatively impact deep focus, especially if you make a mistake and start engaging with the emotions associated with that regret.

Embarrassment – Some students may have felt embarrassed that they did not make the leaderboard, or even that they got answers wrong, or they are slower than others. One student said, "… some people could be embarrassed not shown on the leaderboard..."

This embarrassment can cause negative emotions that may impact a student's deep focus.

General feedback- The feedback given to students was not specific. They were just informed whether the answer was right or wrong. This could have led to students trying to figure out what they did wrong between questions, impacting their overall engagement and focus.

Game familiarity**-** The students played mathematics games on the Kahoot! platform. Some students were unfamiliar with the platform, and even though two 'test runs' of the game and platform were facilitated, these may not have been enough for some students. This could have impacted their concentration and focus.

Game display- During the Kahoot! game, the questions, and answer choices are displayed on the main screen in the classroom. The students read the questions from the screen and then had to answer on their mobile devices. This repeated back and forth from the main screen to the mobile device could have impacted students' deep focus.

Disability – Some students faced accessibility issues during the intervention due to dyslexia. This could have impacted their focus during the activities. For example, the findings reported that reading the questions on the main screen was difficult, and the numbers jumped around, resulting in wrong answer choices. This could have severely impacted the focus of the dyslexic students.

Autonomy – It was identified in the SDT discussion that some students may not have felt completely autonomous. Likert data results confirmed this, as did the focus group data. Lack of autonomy can negatively impact flow. Autonomy is an important component of flow (Biasutti, 2011).

5.3.3.3 Summary of the Flow Theory

All but one of the flow Likert questions obtained above-average mean student feedback. Only five of the students agreed that they were so focused to the point of unawareness. I can, therefore, conclude that the number of students that may have experienced flow would be 5 or less. There is no way of verifying who those 5 students answered the other questions, and hence I cannot explicitly claim that 5 students experienced flow. For flow to happen during an activity, concentration, interest, and enjoyment must occur together (Shernoff et al., 2003; Hamari & Rowe, 2014). The Likert results indicate that most students found the games interesting (90%) and enjoyed them (90%), but it appears that the concentration element did not align, as only (13%) of students agreed that they were completely lost in thought to the point of unawareness.

Many of the factors highlighted above could have impacted the students' concentration and, hence, their flow experience. The literature states that achieving flow in the classroom is not always easy because even if some of the flow elements are in balance, others may not align (Biasutti, 2011).

The findings suggest that the students may not have achieved the full flow state. Despite the students demonstrated skill to match the mathematics challenge, being engaged in the learning process, improving their knowledge of mathematics and overall enjoyment of the GBL activities. Could this mean that the students can still optimise even if they are not in flow, or can the flow state be achieved even when you are not so focused to the point of unawareness? Perttula et al. (2017) state that you can achieve the flow state if all flow dimensions are not aligned. However, this claim is based on a referenced study that reported that athletes experienced approximately 5 of the flow dimensions at a time.

The elements mentioned above can all potentially affect flow due to the fact that they can distract the students, but on the other hand, some people can be in a deeply concentrated state despite distraction; after all, 5 of the students claimed that they became completely lost in thought to the point where they were unaware of themselves.

The idea of students achieving flow despite the distraction is supported by this claim by Csikszentmihalyi (1975, p.55),

> *"Some people, some of the time, appear to be able to enter flow simply by directing their awareness so as to limit the stimulus field in a way that allows the merging of action and awareness. But most people rely on external cues for getting into flow state."*

It would be interesting to explore this further to see what exactly impacted the students' responses. This is a potential area for future game-based research. Future research could delve further into students' perspectives of their experience but take on a research design that observes the students' Likert responses first and then explores further based on the results obtained. This can potentially give a clearer perspective of flow and whether it was achieved despite the non-alignment of some elements.

5.3.4 SDT and Flow Together

Self-determination theory and flow are closely linked (Lüking et al., 2023; Wang & Demerin, 2023). There is reciprocity between them as they coalesce in the GBL classroom, contributing to student positive learning outcomes and overall well-being. In the GBL environment in this intervention, autonomy, competence, and relatedness (SDT) promoted flow, and some elements of flow, such as enjoyment, challenge, skill, and feedback, enhanced SDT. The GBL intervention in this study satisfied the basic psychological needs of autonomy, competence, and relatedness of the students and hence promoted the flow state. Some learners felt autonomous in the GBL environment. The feeling of being in control can encourage deep focus and engagement, facilitating the experience of flow. Lüking et al. (2023) also found their gamified learning environment to be autonomous and conducive to flow. The students also reported feeling competent; this was evidenced by the statistically significant test scores. Competence enhances the potential for flow as individuals who feel competent are more likely to engage in challenges to complement their skills (Lüking et al., 2023), leading to intrinsic reward and enjoyment. The students were particularly convincing on their account of enjoyment; there was 97 % agreement among the students regarding whether they enjoyed the intervention. This further confirms that the GBL environment promoted the flow experience. Lüking et al., (2023) also found that their gamified learning environment promoted competence which positively impacted flow.

Relatedness was also instrumental in promoting flow. Students reported a sense of belonging and camaraderie in their GBL classroom setting. This sense of relatedness can put them at ease and hence make them more likely to enjoy the experience. Students were asked if they enjoyed the GBL experience and, if so, what was the reason; some of the responses indicated that they enjoyed it because they were playing, competing, and interacting with their peers. Enjoyment is a key flow element, and it was one of the main findings of this research. This is contrary to a finding by Lüking et al. (2023), who found that relatedness did not promote flow in their gamified setting.

Lüking et al. (2023) found that autonomy and competence were predictors of flow, but relatedness was not. In the current GBL intervention, the students reported a high level of relatedness (see Table 4.18). Furthermore, they expanded in the open-ended questions and focus groups on the impact relatedness had on them. They said that they enjoyed the GBL intervention because they got to interact with their classmates, fostering connections and camaraderie. This shows a direct link between relatedness and flow (enjoyment). These findings are significant and add valuable information to the discussion of relatedness and its facilitation of flow. Further research is needed to explore the relationship between relatedness and flow.

In line with the mutually reinforcing relationship that flow and SDT share, I will now show how some flow elements contributed to SDT. The students were asked about their enjoyment and reported that they enjoyed the game-based intervention as it made them feel competent and related, hence showing the interrelation between flow and SDT. Another instance of this is that students when faced with challenges, can rise to these challenges, and hence increase their skill and competence, which relates to SDT. Students reported improving their skills in order to navigate the game-based platform effectively. The feedback element of flow can also help to improve competence, which is an element of SDT.

5.3.5 Students' Perceived Benefits and Challenges

Research question 4 explored the benefits and challenges of GBL as students perceived them. The students reported multiple benefits of game-based learning and also some challenges. The benefits far outweighed the challenges. Furthermore, some of the challenges can be mitigated in future research to improve students' experience. In this section, I will arrange the benefits into psychological domains and discuss key benefits and challenge elements.

5.3.5.1 Benefits of Game-Based Learning

Several benefits emerged from analysing the questionnaire data (see Tables 4.25 & 4.27) and the focus group data (see Tables 4.30 & 4.31). Some of the benefits from the questionnaire were repeated and elaborated on by the students in the focus groups. Elements of the self-determination and flow theory were among some of the benefits reported by the students. All of the benefit themes found may be arranged into these 5 domains of educational psychology: developmental theories, learning and motivation, student heterogeneity, classroom instruction, and assessment and evaluation (Schwartz et al., 2022). This gives an impression of how comprehensive and balanced the benefits may be towards overall education and learning. Here are some examples of themes from the analysis of the students' responses classified into the various education psychological domains: developmental theories (relationship and teamwork, familiarity); learning and motivation (autonomy, learning and comprehension, focus and engagement, enjoyment, enhanced confidence, interest, and appeal); student heterogeneity (inclusive); classroom instruction (competition, hands-on, interactive, non-traditional classroom); assessment and evaluation (instant feedback, awareness of progress). Game-based learning literature also reports many benefits of GBL. Some of these include increased student motivation (Gil-Doménech & Berbegal-Mirabent, 2019), improvement in student collaboration (Ting et al., 2019), improvement in learning (Marie et al., 2020), better student satisfaction (Delgado-Gómez et al., 2020), enhanced student engagement (Shaker et al., 2021) and a scaffolding tool (Agbonifo et al., 2021). Below I expand on some of the key benefits themes that were very common among the students' responses.

Motivational benefit **-** Motivation was seen as a key theme due to its vital role in the theoretical framework of SDT underpinning this research. Motivation emerged as a significant theme from the students' responses. The students were motivated by several features of the GBL, including points and a leaderboard- which encouraged them to complete the tasks associated with their course, maintain a high level of performance, progress, and improve. Students said they were motivated by the leaderboard because it was competitive and also because they were collaborating with their peers. In fact, 29 out of 38 students reported that they were motivated by the competitive element of the leaderboard. This is contrary to the findings of Hanus and Fox (2015), who found that the competitive element of leaderboards negatively impacted student motivation. Competition as a motivational element may not have worked in their research, but it does not surprise me that this works in my context. From my experience, competition and leaderboards play an important role in the education system in this region; for example, in some schools, students are placed on leaderboards based on academic performance and are rewarded for top placements, so they are motivated to be at the top. In addition to competition in the education system being a cultural expectation, the students themselves endorse it, so their perception may be different from students in another context. This finding is a prime example of the importance of context in pedagogical approaches. This adds valuable information to the motivation GBL debate. The role of competitive motivation involved in the use of leaderboards could be further explored to determine why it worked in one context but not in another.

In addition to the points and leaderboard, students were also motivated by the digitalized learning environment, which gave them a different learning perspective; the non-traditional learning environment was engaging and held their attention. The games and competition motivated and engaged some students who would have otherwise lost attention and focus. Students advocated for the inclusion of Mathematics GBL in their chemistry courses because they were motivated overall by the GBL intervention.

Time pressure experience - Time pressure emerged as an important feature of this research. It was reported by students as a benefit and also as a challenge. For instance, relating to time pressure as a benefit, students made these comments, "Using games to learn mathematics under a set time influences your skills to learn simple math tricks that you wouldn't forget" and "The speed of the game calls for effective production on the side of the players." Relating to time pressure as a challenge, students said this: "Since the exercise was timed, I felt rushed to complete the questions as fast as I could. Which led me to make mistakes I wouldn't usually make." One student even explained in the focus group that time pressure impacted their autonomy. Negative and positive experiences with time pressure are also reported in the literature. Many learners have a positive perception of the use of Kahoot! but some find the time pressure element challenging (Wang & Tahir, 2020; Cadet, 2023; Wahyuni & Etfita, 2023; Mdlalose et al., 2021). On the other hand, some students appreciated the time pressure element and its impact on their sustained engagement (Alawadhi & Abu-Ayyash, 2021).

5.3.5.2 Challenges of Game-Based Learning

Students had a few challenges involving their experience with game-based learning. It is helpful to acknowledge the challenges students face so that improvements can be made for future interventions. This can also provide vital information to future researchers of game-based learning. Exploring the challenges can also provide insight into what may have impacted students' basic psychological needs (autonomy, competence, and relatedness) and their flow experience. The challenges were observed, grouped under similar categories, and discussed below.

Social challenges in GBL -Several social factors impacted the students' experience of the mathematics game-based learning. For one, the students perceived peer pressure to impact them negatively. For example, on the Kahoot! platform, you can see how many people have already answered the question and how many people remain to answer. This caused students to feel pressured by their peers to choose an answer. If they do not choose an answer quickly, the others may see them as holding up the game, which causes the students to rush due to pressure. This also impacts their autonomy, as it can feel like they are making decisions under duress and not entirely based on their own will. As a result of this, students may end up choosing the wrong answer, leading to frustration, which may impact students' overall experience of flow. One student mentioned that they felt peer pressure when it came to answering questions quickly, as others had already answered. In another instance of social pressure, one student mentioned feeling discouraged by their classmate, but this was on the questionnaire, and there was no further elaboration. Negative emotions attributed to peers can impact your interpersonal relationship with them, hence your relatedness to them. In another instance of social pressure, students felt embarrassed because they were not shown on the leaderboard, (see Table 4.27). The leaderboard can be positive, but some students in this study also thought it had a negative impact on them. Lee et al. (2023) reported on leaderboards' positive and negative impacts. This, in turn, can affect confidence and self-efficacy, further impacting students' competence and relatedness.

Group games can facilitate collaboration, allowing students to exchange their ideas. However, there can also be drawbacks; one student found the group game distracting and felt that miscommunication within the group resulted in the loss of the game. Additionally, depending on the group dynamics, a student can feel less autonomous in a situation like this, especially if there are group members who take control of all the decision-making. On the flip side, a group scenario can also promote autonomy as it may encourage students to participate within the group. One student mentioned, "People can get distracted by the main point of the game-based learning." This is a very interesting observation by the student, and it is also reported in the literature by Herout (2016) that the distraction that comes along with gameplay can be a challenge.

Game platform challenges in GBL – Game platform elements can impact the students' experience of SDT and flow. Game-based learning platforms have their advantages and disadvantages, and so it follows that there are benefits and challenges. Students highlighted the limited feedback provided by Kahoot! as a challenge; the lack of extensive feedback meant students did not know exactly where they went wrong in their calculations or how they may correct it. This can lead to frustration impacting SDT and flow. Gill (2018) reports on the negative potential of instant feedback without reflection as a challenge.

The student/s had some challenges after their mobile device went into sleep mode, and they were bumped off the Kahoot! application and had to repeat the process of creating a character and avatar. Another student was unfamiliar with the game platform at the beginning of the intervention, and they found that challenging. Introductory sessions were implemented at the beginning of the intervention to try to offset some of this. However, the student may have missed the session or did not have enough practice in the introductory sessions.

The setup of the Kahoot! games posed a challenge to some of the students. The questions were displayed on a main screen while they had to respond on their mobile phone; the students found the back and forth from phone to screen and vice versa challenging. This can impact many things, including focus, concentration, and enjoyment. This can be frustrating, especially if you deem the back and forth to be why you incorrectly answer a question.

One student found the scoring system of the platform unjustified since one wrong answer moved them down the leaderboard; this resulted in the student feeling discouraged. Gil-Doménech and Berbegal-Mirabent (2019) also reported that the scoring method for games needs improvement.

The platform does not allow you to go back and change an answer after you click it. Once you choose it, that is it; it is recorded; one student highlighted this as a challenge.

Game content challenges in GBL – Some students reported that the content of the games was easy. This indicates that perhaps they were not challenged enough. In the scope of the flow, an appropriate level of challenge is required to match the skill level to achieve flow. So perhaps this is one reason why the overall flow of the study was affected. Another reported issue relating to game content is that one student felt that if you did not know the content before, then the games were useless, but they were good as a refresher, not for learning new content. The games were, in fact, intended for review and reinforcement purposes, as the students got a review of the content of the games at the beginning of the intervention. If a student missed class that day and did not benefit from that in-class review, they could review the PowerPoint on their own as it was emailed to them.

Time pressure challenges in GBL- Some students find the time pressure element challenging (Wang & Tahir, 2020; Cadet, 2023; Wahyuni & Etfita, 2023; Mdlalose et al., 2021). In the case of this research. some students felt rushed while playing the mathematics games due to the time element associated with the games. The time was preset based on the estimated time a student would be required to complete a question. One student found that the timing element caused him/her to make mistakes they would not make under normal circumstances. Generally, some students felt pressured within the time constraints. However, some became more comfortable as they became more familiar with the timing element, and some did not see the timing as an issue eventually. The time constraints require quick thinking, speed, and dexterity; some students saw this as a challenge that contributed to them making mistakes and feeling pressured. Some students felt that they needed more time to finish the longer questions, and on the other hand, there was frustration among some students while they had to wait for others to finish working out the questions. It is reported in the literature that time pressure affects 'focus and attention' (Lofti et al., 2021), causes distraction (Sianturi & Hung, 2022), and can create apprehension (Mdlalose et al., 2021) and frustration (Lopez & Tucker, 2024) for some students.

Inaccessibility challenges in GBL **-** In a GBL classroom setting, as in any classroom setting, accessibility is an important issue. Classrooms should be accessible so that all learners can benefit equally (Gregory, 2021). It was mentioned previously that some students had accessibility issues regarding the screen due to their dyslexia. The students struggled to read the content on the screen, and they could not access the questions properly in one instance. in another instance, the student responded incorrectly due to the numbers 'jumping around' on the board. Students experiencing barriers to accessing classroom exercises may not have the same opportunities for success as their peers. One common allowance for students with dyslexia is that they are offered extra time to take exams (Gregory, 2021; Duncan & Purcell, 2020). However, this type of allowance would not have been easy or practical in this case. One consideration, in this instance, is the use of another GBL platform that allows students to progress at their own pace outside of strict time constraints; this is a consideration for future research. Gregory (2021) made some interesting claims regarding students with dyslexia and their ability to succeed academically in the HE classroom. He posits that students who possess dyslexic traits use their internal strength and foster creative ways to successfully navigate their barriers as opposed to trying to correct their phonological challenges. Perhaps this was the case for the students in this study; despite the challenges they faced, they still reported enjoying the GBL tasks, so maybe, they used their own strategies to cope in that environment. Future research could also explore the challenges faced by students with dyslexia and some of their coping strategies in GBL environments. The priority here should be a learning environment that is equally accessible to everyone, so research exploring the challenges some students face in the GBL environment can shed valuable light on what is needed to make learning environments accessible to all students.

Lack of autonomy challenges in GBL - During a GBL intervention, students can experience a lack of sustained autonomy due to interference from others around them. For example, when students shout out answers or make comments that influence a student's answer choice, they can feel like they cannot give their 'own input,' impacting their autonomy. One interesting point of view that a student put forward was that a multiple-choice scenario with one correct answer compromises one's autonomy. While the student has a point, my views align more with that of the student who countered and said that despite the one answer choice, you had to employ some form of elimination to arrive at your answer, and hence, the process is autonomous. I think the GBL environment that the students were exposed to supports their autonomy, and the students predominantly felt the same way, as is evidenced by their responses to the questions on autonomy; however, elements such as time pressure and peer distraction can negatively impact autonomy.

5.3.6 Significant Student Recommendations

All students responded that they would recommend including mathematics games in chemistry lessons. Many of them provided a reason for their recommendation. They recommended mathematics game-based learning because they found it a fun and competitive way to learn. The GBL environment provided them with a non-traditional classroom setting that was motivational and engaging, allowing them to increase their confidence. They recommended it as a good starter or review tool, and they saw its relevance in the interdisciplinary context. The students also have some significant recommendations regarding their experience of the GBL intervention and propose some considerations regarding future GBL implementations.

1. Games to be implemented in all classes university-wide to be used as review and practice tools
2. Game-based learning should be all year round
3. Use a different platform that allows more autonomy
4. Include more discussion questions so that students can collaborate and share their knowledge
5. Provide more detailed feedback so students can improve.
6. Include new knowledge, more challenging questions, and more questions in general
7. Include chemistry questions in the games.

5.4 Significance of the Study

To the best of my knowledge, no mixed methods study exploring the impact of mathematics GBL at the HE level takes an interdisciplinary (mathematics and chemistry) approach through the combined lens of the SDT and flow theory, so in that sense, this study is unique, and the findings can contribute to the wider game-based learning discourse, specifically to HE mathematics GBL.

The mixed methods approach adds qualitative and quantitative findings, giving a holistic view of the impact of mathematics GBL in HE. This is important because the findings provide a thorough insight into the viability of mathematics GBL as a suitable pedagogical approach in this and other contexts.

Additionally, the findings contribute to the academic discourse in mathematics game-based learning under the SDT and flow lens. This study adds to the discourse of these theoretical frameworks and extends the dialogue pertaining to GBL use in the mathematics classroom. Therefore, the findings may be used to inform flow and SDT theory and practice. For instance, despite many students indicating that they were not lost to the point of unawareness during the intervention, they still reported that the intervention improved their learning and understanding, and they had fun and did not express many areas of frustration. So, despite not being in flow (or perhaps they were), students had a good learning experience. This finding sets the stage for further investigation of these theoretical frameworks.

This study also has implications for practitioners wishing to integrate game elements that are capable of fostering positive learning experiences and outcomes in their practice as game elements were thoroughly discussed (through SDT and flow lens), which adds to the theoretical discourse and can inform future practice and research directions. For example, the findings of this study indicate that relatedness promotes flow. Since this is contrary to the findings by Lüking et al. (2023), further research could investigate and explain why the findings do not agree; what caused the difference?

Student engagement and motivation remain a much-needed area of concern for educators. The findings obtained in this study suggest that educators can use GBL strategies in their classroom environment to promote motivation and engagement. With the specific reference to flow and SDT, practitioners can tailor their GBL classrooms using findings from this study to optimise the student learning experience.

This is the first research in the Caribbean region that looks at mathematics GBL through the SDT and flow lens. This sets the tone for further theoretically grounded GBL research in this region and globally since my literature analysis indicated a lack of theoretical grounding in mathematics GBL in general. Additionally, the study was conducted in the Cayman Islands. This Caribbean Island provides a unique setting for educational research due to its diverse mix of multiple nationalities among its student population. In addition, the Caribbean region strongly emphasises academic competence in a competitive setting, the ideal pedagogical instrument to investigate among our students. The Cayman Islands is characterised by a dynamic interrelation of socio-economic and cultural factors, which contributes to its uniqueness and makes it an intriguing context for educational research, particularly in the area of mathematics game-based learning, which is understudied in the region. The findings may have significant implications for the Caribbean region, especially since there is a great need to develop pedagogy that enhances mathematics competency. Findings from this study may be generalised and applied to other Caribbean islands and potentially GBL classrooms globally.

There is also interdisciplinary significance to this study. The findings can add to the interdisciplinary STEM dialogue as it shows how mathematics GBL was successfully used to promote learning, motivation, engagement, and enjoyment, among other benefits, in a chemistry classroom. This is vital because there is a need for interdisciplinary approaches as some students struggle to apply the mathematics aspects to their respective disciplines.

This study gave the students a voice; this is important as they get to have a say as to what works for them and what does not. Their feedback can give information about the best options for their learning and well-being and what impacts their learning outcomes. The students recommended that game-based learning be used university-wide in all courses. This suggests that the students enjoyed learning in the GBL environment and want it to continue to benefit themselves and others. The information from their feedback and recommendations can be used as a first step in informing policymakers, administrators, and practitioners of this institution (and others) about which learning environments work for our students in a HE mathematics classroom.

I agree with the students' recommendation on university-wide GBL implementation. This intervention has demonstrated that the inclusion of GBL in classrooms is beneficial (for example, motivation, engagement, competence, and enjoyment) to teaching and learning and can have far-reaching consequences for mathematics learning environments. The insights provided by the findings are significant and should be considered when crafting educational policies.

5.5 Core Contributions

This thesis is important because it addresses several critical gaps in game-based learning that remain unexplored or underexplored despite significant GBL research in recent years.

In section 5.4 (above), I discussed the significance of this thesis. In this section, I summarise the core contributions this thesis makes to new knowledge and provide insights based on the findings of this research.

The core contributions of this thesis are as follows:

1. This thesis contributes to the GBL discourse under the combined lens of flow and SDT. While there has been much GBL research, including some with theoretical underpinnings, research examined through the combined lens of flow and SDT remains underexplored, so this study contributes valuable insight to this emerging discourse. It was shown in the thesis that a classroom that promotes flow and SDT could facilitate learning, enjoyment and engagement.

2. Lüking et al. (2023) concluded in their study that relatedness was not a predictor of flow. My findings in this thesis indicate that relatedness enhances flow. Students reported that one of the reasons they enjoyed the GBL intervention was that they were interacting with their peers (see section 5.3.2.2), which gives a direct link between relatedness and flow. This demonstration of the direct link between relatedness and flow is significant and contributes to the theoretical discussion of SDT and flow.

3. Hanus & Fox (2015) found that leaderboards and competition do not improve educational outcomes and can negatively impact student motivation. In this intervention, the students were motivated by the competitive elements of game-based learning (see Table 4.23), and it was shown that they reported several improvements in their academic outcomes. There was an improvement in competence (see Section 4.3.2.1 and Table 4.15) and development of new skills such as quick thinking and improvement in speed while calculating (see Table 4.27), attributed to the game-based intervention, which used competitive elements. The findings above demonstrate a link between student motivation and competitive game elements, as well as improvement in skills because of competition, which are significant and contribute to understanding classroom learning in the Caribbean context. Competition is an integral part of the education system in the region, and most students thrive in a competitive environment.

4. Kahoot! has been widely used in educational research, for example, Setiawan (2020) explored Kahoot! to improve mathematics learning motivation of elementary school students, Prieto et al., (2019) allowed secondary students to assess the use of Kahoot! in the learning process of STEM education and Shaker et al., (2021), investigated the use of Kahoot! on undergraduate Statistics students' anxiety and confidence. However, its application in an interdisciplinary context remains underexplored. This study contributes to this body of knowledge and provides interdisciplinary insights into Kahoot! in the mathematics/chemistry classroom. Students reported that the mathematics games used in the classrooms (facilitated by the Kahoot! platform) had interdisciplinary benefits; they noted enhanced comprehension of the chemistry content because of the mathematics games (see Table 4.29).

5. The study revealed that games in the classroom promote collaboration (see Table 4.31), students enjoy game-based learning (see Table 4.29), and games can promote understanding of mathematical concepts (see Table 4.29). This confirms and extends the understanding of the work of researchers such as Gil-Doménech & Berbegal-Mirabent (2019), Suparlan et al. (2019), Zabala-Vargas et al. (2021), who have shown that games promote collaboration; Koparan (2019) and Kaedah et al. (2020), who concluded that games enhance student enjoyment; Gil-Doménech & Berbegal-Mirabent (2019), Ting et al. (2019) and Marie et al. (2020), who emphasised that games can enhance the understanding of mathematical concepts. By adding these insights within an interdisciplinary higher education Caribbean context, this study demonstrates that the benefits identified in previous research are also evident in my setting, thereby extending the applicability of game-based learning to this context.

6. The benefits of GBL are well documented in various studies (Suparlan et al., 2019; Shaker et al., 2021; Delgado-Gomez et al., 2020). However, there is an underrepresentation in the existing literature regarding the challenges students face, from their perspective, in a higher education interdisciplinary (mathematics/chemistry) context. This thesis contributes to extending the knowledge and understanding of games in the higher education interdisciplinary classroom and highlights challenges from the students' point of view. Through

the qualitative analysis of open-ended questionnaires and focus group discussions, this research was able to unearth students' views on their experiences during the intervention. The findings obtained point to several barriers experienced by the students, such as peer pressure, time pressure, lack of autonomy, game content not being fully accessible to some with specific disabilities, miscommunication during group games and knowledge gaps (see Tables 4.28 and 4.30). These findings provide a critical and learner-centred view of GBL interventions. This adds to the body of knowledge of game-based learning effectiveness and informs design implications for educational games and game platforms. These findings also contribute to the practical implementation of future GBL interventions. By demonstrating the experiences of learners and the challenges they face during the intervention, this study provides practical insights that may be used by various stakeholders, including educators, curriculum designers and game developers. Overall, the findings regarding students' challenges during the GBL intervention add to the underrepresented perspective of students' voices and contribute meaningful insights to the higher education GBL discussions by highlighting the significance of factors that affect learners' experiences during education games at that level.

7. Findings from the students' perceived challenges also contribute valuable information to the discourse of flow and SDT. For example, students reported a lack of autonomy (see Table 4.30) as one of the challenges. Compromised autonomy negatively impacts both flow and SDT. So, suppose a practitioner wishes to facilitate flow and/or SDT in the classroom. In that case, this thesis provides valuable insights into factors that are likely to have a negative impact on these two theoretical frameworks.

8. Another important challenge highlighted by the students is varying levels of inaccessibility to the games during gameplay due to disability-dyslexia (see Table 4.32). This study underscores the necessity for pedagogical inclusivity in game-based learning environments, highlighting the importance of accommodating diverse learning needs. Accessibility in the classroom is a paramount issue, and this thesis contributes to that conversation. If content

accessibility is compromised, it would likely negatively impact flow and SDT. Gregory (2021) suggests that students who possess dyslexic traits use their internal strength and foster creative ways to successfully navigate their barriers, which is probably true, but despite this, the students in this study highlighted their dyslexia as a challenge. I believe classrooms should be accessible for all learners, and students should not have to navigate dyslexic barriers on their own.

9. Another key contribution of this thesis is the students' recommendations given after the mathematics game-based intervention. Students were positioned not only as learners but also as a critical source of reflective information. Much of the literature on mathematics GBL is focused on the benefits of GBL, such as (Nurul Hasana, 2018; Gil-Doménech & Berbegal-Mirabent, 2019; Koparan, 2019; Shaker et al., 2021). There is a notable underrepresentation of students' reflective contributions to game elements and pedagogical improvements in the literature, especially in an interdisciplinary HE context, which is underexplored. This research responds to that gap by facilitating a platform for students to provide their recommendations. Students' reflective recommendations are significant as they provide valuable information to practitioners, curriculum designers and other education stakeholders. These recommendations include a call for university-wide GBL as a review and practice tool, GBL to be used to disseminate new knowledge, exploration of other game platforms that promote autonomy, inclusion of more collaborative questions so learners can work together, providing more detailed feedback on the game questions, and including chemistry questions (see Tables 4.30 and 4.33). The students' recommendations highlighted the elements of SDT and flow, further emphasising this thesis's contribution to the flow and SDT discourse. Student recommendations are student-centred and demonstrate how students can help refine pedagogical tools and provide actionable guidance to future researchers, education practitioners and other education stakeholders.

5.6 Limitations of the Study

I have identified four limitations of this study. Discussing these provides information regarding the constraints of this study.

1. Firstly, the intervention was not very accessible to at least two of the students who mentioned dyslexia. This could have impacted their experience with the GBL intervention. Future studies should consider all accessibility issues at the design stage and be prepared to accommodate all students.
2. Another limitation is that of the Kahoot! game platform that was used in the intervention; while the platform was positive in most cases, it had a huge impact on the student's autonomy, which was closely linked to both theoretical frameworks used in this study and may have impacted the feedback given on autonomy, for example.
3. A third potential limitation is the duration of GBL engagement; while the students got a few chances to play the games, they did not play them for long, as there were only a few questions on each game. Could this have affected their experience of flow? On the other hand, could a longer session lead to boredom?
4. This study could have taken an explanatory sequential mixed methods design (2 phases) approach rather than a convergent mixed methods approach (Creswell & Creswell, 2018). The former would have provided more insight into students' views, especially on areas with low scoring for the mean since there would have been a chance beforehand to analyse the quantitative results before using the qualitative data methods to bring more insights to the findings.

5.7 Opportunities for Future Research

These are some of the future research considerations that are being contemplated as a result of the findings:

1. Firstly, the study determined that students had an above-average mean final grade from the previous cohort. However, this did not tell how well the students integrated the mathematics they learned into chemistry. Future research could

observe students' actual exam papers to see how well mathematics was applied in specified areas covered in the GBL activities.

2. Secondly, the findings show that some students may not have experienced flow. Some elements were highlighted as potential reasons for this; future research could re-examine flow, with careful planning at the design stages, to mitigate any potential distractions students faced and to investigate why they did not engage to the point that they were not aware of themselves.

3. On the other hand, some students did report one element of flow that most students did not. Only five students reported feeling engaged to the point where they were not aware of themselves. It would be interesting to find out how they were able to achieve this state while others in the same environment were not. A research design that first explores students' Likert responses to flow questions after a GBL intervention could be used; after the analysis of these responses, probing focus groups or interviews could follow to shed light on the Likert responses.

4. Another point of potential exploration is whether students experienced flow despite the non-alignment of all the flow elements. A more in-depth analysis of flow could be conducted in future research to determine if students can, in fact, achieve flow in the mathematics classroom if they experience some but not all of the flow elements.

5. As a result of the findings regarding flow and relatedness, it would be a good idea to explore this further. It was found that relatedness impacts flow in my research, while another finding in another research (Lüking et al., 2023) showed the opposite. Exploring the extent of the impact and why it did not work in another context would add value to the discussion.

6. Another finding that was contrary to that of the literature is that a researcher found that the competitive element of the leaderboard did not motivate students (Hanus & Fox, 2015). Since this study concludes the opposite, further investigation could attempt to demonstrate the presence of motivational

competition in our education system and explore how this may be used in a GBL context to motivate students on an ongoing basis or even delve into the extent and type of motivation associated with competitive leaderboards in GBL.

7. Additionally, it was clear that students felt that the intervention benefited them in many ways. However, it would be interesting to investigate students' self-efficacy before and after the intervention. Does GBL impact students' self-efficacy in relation to mathematics?

8. The findings of this study are promising. Students even recommended GBL implementation schoolwide. A future study could investigate educators' perceptions of GBL implementation in their classrooms. The findings of which can inform practice in this context.

9. A future study could also explore GBL in a differentiated and accessible classroom. This study revealed that some students needed more time while others felt that their classmates were too slow. Some students struggled to see the screen due to their disability. How does GBL work when catering to different abilities and ensuring the classroom is accessible to everyone?

10. Extending on the above point, future research could also explore challenges faced and coping strategies used by students with dyslexia and other disabilities. This information will be useful when planning future game interventions and also contribute to developing an environment that is accessible to everyone.

11. This study used GBL as a review instrument rather than an instrument to teach mathematics. It would be interesting to explore GBL as a tool to disseminate new knowledge and see its impact on teaching and learning.

12. It would be interesting to replicate this research but use a different game platform, such as Quizizz[1] which gives more autonomy, and then compare the findings regarding autonomy and flow.

5.8 Reflections and Lessons Learnt

This intervention went well overall. However, I would make some further considerations if I repeated this study.

- Firstly, I would find out if any students had accessibility issues in the classroom. If there were, I would use Kahoot!'s new accessibility features to ensure those students have an experience like the other students or use another platform that suits all the learners in the classroom. In this research, it turned out that a couple of students had dyslexia, and it impacted their overall experience. In the future, I would mitigate accessibility issues by using features such as Kahoot!'s "High contrast mode", which enhances colour and makes it easier to read, and the "live game viewing option", which displays questions and answers on the player's device.
- Another consideration I would make relates to the students' feedback on time and peer pressure. Some students felt pressured by the time given to do each question and by their classmates. To mitigate this, I would consider using another platform, such as Wayground, that allows students to work at their own pace, so that they would not feel rushed or that others are too slow. This would also give students more autonomy. Students highlighted this lack of autonomy as one of the challenges they faced during the intervention.
- One student mentioned that embarrassment could result if you are not on the leaderboard. In a future game-based intervention, I would include other means of allocating points to the students so that they would have multiple ways of getting points during the game intervention, and it would not be solely based on the leaderboard. For example, I could award points for streaks or progress points, like 3 in a row. There could also be the option of removing the leaderboard, and this may be a good solution in some contexts. I could also walk

[1] Quizizz has been renamed to Waygound. www.wayground.com

around the classroom and motivate and encourage students so they do not feel left out.

- Students also reported that the feedback given was not enough. During the intervention, feedback was limited to indicating whether multiple-choice responses were right or wrong, without providing thorough explanations. In a future intervention, I would provide detailed feedback for each question to help students understand where they went wrong. This would support the development of their learning and competence.

5.9 Conclusion

This study investigated the impact of mathematics game-based learning on students' academic performance, basic psychological needs of autonomy, competence, and relatedness, and their flow experience. It also aimed to give students' perceptions of the benefits and challenges of mathematics game-based learning in their chemistry classroom. It was found that the mathematics game-based intervention had a statistically significant impact on students' pretest to posttest grades and did not impact their course grades negatively. The findings also suggest that students' basic psychological needs of autonomy, competence, and relatedness were being met (for the most part) with the execution of the intervention. Additionally, some students may have experienced flow while playing the math games. Benefits, challenges, and recommendations were presented from the students' point of view. Overall, the students overwhelmingly enjoyed the GBL intervention; they were motivated and engaged in the learning environment and improved their mathematics skills and competencies. The GBL environment facilitated SDT and flow and impacted the students' overall learning experience and well-being.

This study has demonstrated that mathematics GBL facilitates flow, and SDT can transform classrooms. Although the study was conducted at the higher education level, the findings may be applicable to all education levels and may very well be the innovative response needed in the Caribbean to facilitate optimal learning experiences and outcomes.

References

Abdu, R., Schwarz, B., & Mavrikis, M. (2015). Whole-class scaffolding for learning to solve mathematics problems together in a computer-supported environment. *ZDM - Mathematics Education*, *47*(7), 1163–1178. https://doi.org/10.1007/s11858-015-0719-y

Agbonifo, O. C., Akinwonmi, A. E., & Williamson, S. (2021). Design of a Digital Game-Based Learning Environment for Solving Quadratic Equations Using Completing-the-Square-Method. *International Journal of Computer (IJC) International Journal of Computer (IJC*, *40*(1), 66–82. http://ijcjournal.org/

Alaswad, Z., & Nadolny, L. (2015). Designing for Game-Based Learning: The Effective Integration of Technology to Support Learning. *Journal of Educational Technology Systems*, *43*(4), 389–402. https://doi.org/10.1177/0047239515588164

Alawadhi, A., & Abu-Ayyash, E. A. S. (2021). Students' perceptions of Kahoot!: An exploratory mixed-method study in EFL undergraduate classrooms in the UAE. *Education and Information Technologies*, *26*(4), 3629–3658. https://doi.org/10.1007/s10639-020-10425-8

Almeida, F., & Buzady, Z. (2019). Assessment of entrepreneurship competencies through the use of fligby. *Digital Education Review*, *35*, 151–169. https://doi.org/10.1344/der.2019.35.151-169

Anastasiadis, T., Lampropoulos, G., & Siakas, K. (2018). Digital Game-based Learning and Serious Games in Education. *International Journal of Advances in Scientific Research and Engineering*, *4*(12), 139–144. https://doi.org/10.31695/ijasre.2018.33016

Anthony, G. (2000). Factors influencing first-year students' success in mathematics. *International Journal of Mathematical Education in Science and Technology*, *31*(1), 3–14. https://doi.org/10.1080/002073900287336

Aqilah, N., Yusof, M., & Shahrill, M. (2021). The Effects of Non-Digital Game-Based Learning on Brunei Darussalam Students' Mathematical Perspectives and Achievements. In *Southeast Asian Mathematics Education Journal* (Vol. 11, Issue 1).

Azadvar, A., & Canossa, A. (2018, August 7). UPEQ: Ubisoft perceived experience questionnaire: A self-determination evaluation tool for video games. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3235765.3235780

Bakker, A., Cai, J., & Zenger, L. (2021). Future themes of mathematics education research: an international survey before and during the pandemic. *Educational Studies in Mathematics*, *107*(1). https://doi.org/10.1007/s10649-021-10049-w

Balasubramanian, N., & Sudha Rani, S. (2023). Reliability Measurements: Methods And Estimation In Healthcare Research. *International Journal of Research and Analytical Reviews*, 10(4), 843-861. http://www.ijrar.org/IJRAR23D1485.pdf

Balliu, V. & Belshi, M. (2017). *Modern Teaching Versus Traditional Teaching-Albanian Teachers Between Challenges and Choices*. *2*(4). European Journal of Multidisciplinary Studies, 2(4), 20-26. https://doi.org/10.26417/ejms.v4i4.p20-26

Bans-Akutey, A., & Tiimub, B. M. (2021). *Triangulation in research*. Academia Letters, Article 3392. https://doi.org/10.20935/AL3392

Beck, A. L., Chitalia, S., & Rai, V. (2019). Not so gameful: A critical review of gamification in mobile energy applications. *Energy Research and Social Science*, *51*, 32–39. https://doi.org/10.1016/j.erss.2019.01.006

Ben C. (n.d.). *A CASE FOR FLOW STATE*. https://www.oxbowschool.org/assets/gallery/os36-final-projects/docs/ben-c-os36paper.pdf

Biasutti, M. (2011). Flow and optimal experience. In M. A. Runco & S. R. Pritzker (Eds.), Encyclopedia of creativity (2nd ed., Vol. 1, pp. 522–528). Academic Press. https://doi.org/10.1016/B978-0-12-375038-9.00099-6

Bitrián, P., Buil, I., & Catalán, S. (2020). Flow and business simulation games: A typology of students. *International Journal of Management Education*, *18*(1). https://doi.org/10.1016/j.ijme.2020.100365

Bortot, P., & Coles, S. (2019). A statistical learning exercise based on a modified Rock-Paper-Scissors game. *MSOR Connections*, *18*(1), 56–65. https://doi.org/10.21100/msor.v18i1.1032

Braun, V., & Clarke, V. (2021). Conceptual and Design Thinking for Thematic Analysis. *Qualitative Psychology*, *9*(1), 3–26. https://doi.org/10.1037/qup0000196

Brezovszky, B., McMullen, J., Veermans, K., Hannula-Sormunen, M. M., Rodríguez-Aflecht, G., Pongsakdi, N., Laakkonen, E., & Lehtinen, E. (2019). Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge. *Computers and Education*, *128*, 63–74. https://doi.org/10.1016/j.compedu.2018.09.011

Cadet, M. J. (2023). Application of game-based online learning platform: Kahoot a formative evaluation tool to assess learning. *Teaching and Learning in Nursing*, *18*(3), 419–422. https://doi.org/10.1016/j.teln.2023.03.009

Camacho-Sánchez, R., Rillo-Albert, A., & Lavega-Burgués, P. (2022). Gamified Digital Game-Based Learning as a Pedagogical Strategy: Student Academic Performance and Motivation. *Applied Sciences (Switzerland)*, *12*(21). https://doi.org/10.3390/app122111214

Caribbean Examinations Council (2020). *CSEC ® Mathematics*. https://www.cxc.org/cxc-annual-report-2020/

Caribbean Examination Council. (2022). *CSEC ® Mathematics* https://www.cxc.org/cxc-annual-report-2022/

Catalán, S., Martínez, E., & Wallace, E. (2019). Analysing mobile advergaming effectiveness: the role of flow, game repetition and brand familiarity. *Journal of Product and Brand Management*, *28*(4), 502–514. https://doi.org/10.1108/JPBM-07-2018-1929

Chan, G., Arya, A., Orji, R., & Zhao, Z. (2019). Motivational strategies and approaches for single and multi-player exergames: A social perspective. *PeerJ Computer Science*, *5*, 1–34. https://doi.org/10.7717/PEERJ-CS.230

Chen, P. Y., Hwang, G. J., Yeh, S. Y., Chen, Y. T., Chen, T. W., & Chien, C. H. (2022). Three decades of game-based learning in science and mathematics education: an integrated bibliometric analysis and systematic review. *Journal of Computers in Education*, *9*(3), 455–476. https://doi.org/10.1007/s40692-021-00210-y

Chiu, T. K. F. (2022). Applying the self-determination theory (SDT) to explain student engagement in online learning during the COVID-19 pandemic. *Journal of Research on Technology in Education*, *54*(S1), S14–S30. https://doi.org/10.1080/15391523.2021.1891998

Christopher, A. N. (2020). Interpreting and Using Statistics in Psychological Research. In *Interpreting and Using Statistics in Psychological Research*. SAGE Publications, Inc. https://doi.org/10.4135/9781506304144

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE.

Croft, T., Grove, M., & Lawson, D. (2022). The importance of mathematics and statistics support in English universities: an analysis of institutionally-written regulatory documents. *Journal of Higher Education Policy and Management*, *44*(3), 240–257. https://doi.org/10.1080/1360080X.2021.2024639

Csikszentmihalyi, M. (1975). Play and Intrinsic Rewards. *Journal of Humanistic Psychology*, *15*(3), 41–63. https://doi.org/10.1177/002216787501500306

Csikszentmihalyi, M. (1998). *Finding Flow: The Psychology of Engagement With Everyday Life*. https://www.researchgate.net/publication/200026151

De Troyer, O., Lindberg, R., & Sajjadi, P. (2019). TrueBiters, an educational game to practice the truth tables of propositional logic: Development, evaluation, and lessons learned. *Smart Learning Environments*, *6*(1). https://doi.org/10.1186/s40561-019-0105-2

Deci, E. L., & Ryan, R. M. (1985). The general causality orientations scale: Self-determination in personality. *Journal of Research in Personality, 19*(2), 109–134. https://doi.org/10.1016/0092-6566(85)90023-6

Delgado-Gómez, D., González-Landero, F., Montes-Botella, C., Sujar, A., Bayona, S., & Martino, L. (2020). Improving the teaching of hypothesis testing using a divide-and-conquer strategy and content exposure control in a gamified environment. *Mathematics*, *8*(12), 1–14. https://doi.org/10.3390/math8122244

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). *From game design elements to gamefulness: defining "gamification". Proceedings of the 15th International Academic MindTrek Conference Envisioning Future Media Environments (pp. 9-15)*. ACM Digital Library.

Dimitrov, D. M., & Rumrill, P. D. (2003). Pretest-posttest designs and measurement of change. In *Work* (Vol. 20). IOS Press.

Dorier, J.-L. (2010). *Mathematics in its relation to other disciplines: Some examples related to economics and physics* (Vol. 2, Issue 1). https://doi.org/10.61174/recacym.v2i1.150

Duncan, H., & Purcell, C. (2020). Consensus or contradiction? A review of the current research into the impact of granting extra time in exams to students with specific learning difficulties (SpLD). *Journal of Further and Higher Education*, *44*(4), 439–453. https://doi.org/10.1080/0309877X.2019.1578341

Ekici, M. (2021). A systematic review of the use of gamification in flipped learning. *Education and Information Technologies*, *26*(3), 3327–3346. https://doi.org/10.1007/s10639-020-10394-y

Elangovan, N., & Sundaravel, E. (2021). Method of preparing a document for survey instrument validation by experts. *MethodsX*, *8*. https://doi.org/10.1016/j.mex.2021.101326

Elsattar, H. K. H. A. (2018). Designing for game-based learning model: The effective integration of flow experience and game elements to support learning. *Proceedings - 2017 14th International Conference on Computer Graphics, Imaging and Visualization, CGiV 2017*, 34–43. https://doi.org/10.1109/CGiV.2017.31

Engeser, S. (Ed.). (2014). Advances in flow research. Springer. https://doi.org/10.1007/978-1-4614-2359-1

Ernest, P., Skovsmose, O., van Bendegem, J. P., Bicudo, M., Miarka, R., Kvasz, L., & Moeller, R. (2016). *The Philosophy of Mathematics Education, ICME-13 Topical Surveys*. https://link.springer.com/book/10.1007/978-3-319-40569-8

Eyyam, R., & Yaratan, H. S. (2014). Impact of Use of Technology in Mathematics Lessons on Student Achievement and Attitudes. *Social Behavior and Personality: An International Journal*, *42*(1), 31S-42S. https://doi.org/10.2224/sbp.2014.42.0.s31

Farrell, D., & Moffat, D. C. (2014). *Applying the self determination theory of motivation in games based learning* https://www.researchgate.net/publication/287379628

Feilzer, M. Y. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, *4*(1), 6–16. https://doi.org/10.1177/1558689809349691

Fein, E. C., Gilmour, J., Machin, T., And,;, & Hendry, L. (2022). *Statistics for Research Students*. www.jamovi.org.

Fetters, M. D., & Molina-Azorin, J. F. (2017). The Journal of Mixed Methods Research Starts a New Decade: The Mixed Methods Research Integration Trilogy and Its Dimensions. In *Journal of Mixed Methods Research* (Vol. 11, Issue 3, pp. 291–307). SAGE Publications Inc. https://doi.org/10.1177/1558689817714066

Fleming, J. (2018). Recognizing and resolving the challenges of being an insider researcher in work-integrated learning. *International Journal of Work-Integrated Learning, 19*(3), 311–320. https://www.ijwil.org/files/IJWIL_19_3_311_320.pdf

Fogel, A., de Sousa, D., Padrão, P., & Azevedo, J. (2021). Failures in game-based learning experiences sometimes win. *Proceedings of the European Conference on Games-Based Learning*, *2021-September*, 203–212. https://doi.org/10.34190/GBL.21.080

Foss, B., Løkken, A., Leland, A., Stordalen, J., Mordt, P., & Oftedal, B. F. (2014). Digital game-based learning: A supplement for medication calculation drills in nurse education. *E-Learning and Digital Media*, *11*(4), 342–349. https://doi.org/10.2304/elea.2014.11.4.342

Gallagher, M. A., Parsons, S. A., & Vaughn, M. (2022). Adaptive teaching in mathematics: a review of the literature. In *Educational Review* (Vol. 74, Issue 2, pp. 298–320). Routledge. https://doi.org/10.1080/00131911.2020.1722065

Gil-Doménech, D., & Berbegal-Mirabent, J. (2019). Stimulating students' engagement in mathematics courses in non-STEM academic programmes: A game-based learning. *Innovations in Education and Teaching International*, *56*(1), 57–65. https://doi.org/10.1080/14703297.2017.1330159

Gill, H. (2018). *Gamification and game-based learning-is it the future of education ?* https://www.researchgate.net/publication/331036445

Goehle, G., & Wagaman, J. (2016). The Impact of Gamification in Web Based Homework. *PRIMUS*, *26*(6), 557–569. https://doi.org/10.1080/10511970.2015.1122690

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2003.1870

Grasse, K. M., Kreminski, M., Wardrip-Fruin, N., Mateas, M., & Melcer, E. F. (2022). Using Self-Determination Theory to Explore Enjoyment of Educational Interactive Narrative Games: A Case Study of Academical. *Frontiers in Virtual Reality*, *3*. https://doi.org/10.3389/frvir.2022.847120

Greipl, S., Moeller, K., & Ninaus, M. (2020). Potential and limits of game-based learning. *International Journal of Technology Enhanced Learning*, *12*(4), 363–389. https://doi.org/10.1504/IJTEL.2020.110047

Gündüz, A. Y., & Akkoyunlu, B. (2020). Effectiveness of Gamification in Flipped Learning. *SAGE Open*, *10*(4). https://doi.org/10.1177/2158244020979837

Hamari, J., & Rowe, E. (2014). *Measuring Flow in Educational Games and Gamified Learning Environments*. https://www.researchgate.net/publication/264046054

Hamid, S. H., Zulkiply, N., & Mohamad, F. S. (2022). The Effects of Non-Digital Game-Based Learning and Cognitive Level of Questions on Isometric Transformations. *Asian Journal of University Education*, *18*(1), 34–50. https://doi.org/10.24191/ajue.v18i1.17167

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers and Education*, *80*, 152–161. https://doi.org/10.1016/j.compedu.2014.08.019

Hassan, H. G., & Shkak, J. (2020). *Characteristics of Normal Distribution*. https://doi.org/10.13140/RG.2.2.19914.59846

Heller, P., & Pogaru, P. (2021). A novel approach to teaching Hidden Markov Models to a diverse undergraduate population. *Heliyon*, *7*(3), e06437. https://doi.org/10.1016/j.heliyon.2021.e06437

Herout, L. (2016). *Application of gamification and game-based learning in education*. 8th International Conference on Education and New Learning Technologies, July 2016, Barcelona, Spain. http://dx.doi.org/10.13140/RG.2.1.1513.3680

Holden, J. I. (2016). *Mobile inquiry-as-play in mathematics teacher education*. *On the Horizon, 24*(1), 71–81. https://doi.org/10.1108/OTH-08-2015-0046

Isham, A., & Jackson, T. (2022). Finding flow: exploring the potential for sustainable fulfilment. In *The Lancet Planetary Health* (Vol. 6, Issue 1, pp. e66–e74). Elsevier B.V. https://doi.org/10.1016/S2542-5196(21)00286-2

Itter, D., & Meyers, N. (2017). *Fear, loathing and ambivalence toward learning and teaching mathematics: Preservice teachers' perspectives* (Vol. 19).

Jääskä, E., & Aaltonen, K. (2022). Teachers' experiences of using game-based learning methods in project management higher education. *Project Leadership and Society*, *3*. https://doi.org/10.1016/j.plas.2022.100041

Jalil, H. A., Nasharuddin, N. A., Erzam, E., Mohd Nazan, A. I. N., Ismail, I. A., Ma'rof, A. M., Mohd Rusdi, N. A. F., & Zaremohzzabieh, Z. (2020). Systematic Review of Enjoyment Element in Health-Related Game-Based Learning. *International Journal of Emerging Technologies in Learning*, *15*(21), 40–57. https://doi.org/10.3991/ijet.v15i21.17345

Jones, E., Priestley, M., Brewster, L., Wilbraham, S. J., Hughes, G., & Spanner, L. (2021). Student wellbeing and assessment in higher education: the balancing act. *Assessment and Evaluation in Higher Education*, *46*(3), 438–450. https://doi.org/10.1080/02602938.2020.1782344

Juhari, A. N., & Abu Bakar, M. H. (2020). Popular Game Elements Used in Designing Game-Based Learning STEM Application for School Students – A Review. *Jurnal Kejuruteraan*, *32*(4), 559–568. https://doi.org/10.17576/jkukm-2020-32(4)-01

Junior, E., Reis, A. C. B., Mariano, A. M., Barros, L. B., Júnior, E. S., Carla Reis, A. B., de Almeida Moysés, D., & Marinho Avelino da Silva, C. (2019). *Systematic literature review of gamification and game-based learning in the context of problem and project based learning approaches*. 11th International Symposium on Project Approaches in Engineering Education (PAEE), 16th Active Learning in Engineering Education Workshop (ALE), June 2019, Hammamet, Tunisia. https://www.researchgate.net/publication/334046201

Kaedah, K., Tentang, G., Belajar Atas Talian, K., Berasaskan, M., Dalam Kalangan, S., Matematik, P., Menggunakan, Y., Gamifikasi, P., Pembelajaran, O., & Khalid Norzalina, N. (2020). *A Mixed Method Study on Online Learning Readiness and Situational Motivation among Mathematics Students using Gamified Learning Objects*. https://doi.org/10.17576/islamiyyat-2020-42IK-04

Karakuş, F., & Baki, A. (2020). From Chaotic to Order: Using Chaos Game in Mathematics Teaching. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*. https://doi.org/10.16949/turkbilmat.541136

Karamert, Ö., & Kuyumcu Vardar, A. (2021). The Effect of Gamification on Young Mathematics Learners' Achievements and Attitudes. *Journal of Educational Technology and Online Learning*. https://doi.org/10.31681/jetol.904704

Karanezi, X., & Rapti, E. (2015). Teachers' Attitudes and Perceptions: Association of Teachers' Attitudes toward Traditional and Modern Teaching Methodology According to RWCT as Well as Teachers' Perceptions for Teaching as a Profession. *Creative Education*, *06*(06), 623–630. https://doi.org/10.4236/ce.2015.66061

Kayser, D., Perrig, S. A. C., & Brühlmann, F. (2021). Measuring players' experience of need satisfaction in digital games: An analysis of the factor structure of the UPEQ. *CHI PLAY 2021 - Extended Abstracts of the 2021 Annual Symposium on Computer-Human Interaction in Play*, 158–162. https://doi.org/10.1145/3450337.3483499

Kennedy, K. J., & Lee, J. C.-K. (2018). *Routledge International Handbook of Schools and Schooling in Asia*.

Koparan, T. (2019). Teaching Game and Simulation Based Probability. *International Journal of Assessment Tools in Education*, 235–258. https://doi.org/10.21449/ijate.566563

Koparan, T. (2021). The impact of a game and simulation-based probability learning environment on the achievement and attitudes of prospective teachers. *International Journal of Mathematical Education in Science and Technology*. https://doi.org/10.1080/0020739X.2020.1868592

Kowal, J., & Fortier, M. S. (1999). Motivational determinants of flow: Contributions from self-determination theory. *Journal of Social Psychology*, *139*(3), 355–368. https://doi.org/10.1080/00224549909598391

Krath, J., Schürmann, L., & von Korflesch, H. F. O. (2021). Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior*, *125*. https://doi.org/10.1016/j.chb.2021.106963

Krouska, A., Troussas, C., & Sgouropoulou, C. (2022). Mobile game-based learning as a solution in COVID-19 era: Modeling the pedagogical affordance and student interactions. In *Education and Information Technologies* (Vol. 27, Issue 1, pp. 229–241). Springer. https://doi.org/10.1007/s10639-021-10672-3

Kwon, H. Y., & Özpolat, K. (2021). The dark side of narrow gamification: Negative impact of assessment gamification on student perceptions and content knowledge. *INFORMS Transactions on Education*, *21*(2), 67–81. https://doi.org/10.1287/ITED.2019.0227

Kyriazos, T. A., Stalikas, A., Prassa, K., Galanakis, M., Flora, K., & Chatzilia, V. (2018). The Flow Short Scale (FSS) Dimensionality and What MIMIC Shows on Heterogeneity and Invariance. *Psychology*, *09*(06), 1357–1382. https://doi.org/10.4236/psych.2018.96083

Lake, W., Wallin, M., Woolcott, G., Boyd, W., Foster, A., Markopoulos, C., & Boyd, W. (2017). Applying an alternative mathematics pedagogy for students with weak mathematics: meta-analysis of alternative pedagogies. *International Journal of Mathematical Education in Science and Technology*, *48*(2), 215–228. https://doi.org/10.1080/0020739X.2016.1245876

Lataster, J., Reijnders, J., Janssens, M., Simons, M., Peeters, S., & Jacobs, N. (2022). Basic Psychological Needs Satisfaction and Well-Being Across Age: A Cross-Sectional General Population Study among 1709 Dutch Speaking Adults. Journal of Happiness Studies, 23(5), 2259-2290. https://doi.org/10.1007/s10902-021-00482-2

Leacock, C. (2015). Status of Mathematics Education in the Eastern Caribbean: Issues and Possible Solutions for Teacher Preparation and Support. *Journal of Eastern Caribbean Studies*, *40*(3).

Lee, J. Y., Pyon, C. U., & Woo, J. (2023). Digital Twin for Math Education: A Study on the Utilization of Games and Gamification for University Mathematics Education. *Electronics (Switzerland)*, *12*(15). https://doi.org/10.3390/electronics12153207

Li, Q., Cho, H., Cosso, J., & Maeda, Y. (2021). Relations Between Students' Mathematics Anxiety and Motivation to Learn Mathematics: a Meta-Analysis. *Educational Psychology Review*, *33*(3), 1017–1049. https://doi.org/10.1007/s10648-020-09589-z

Lofti, T. M., Pratolo, B. W., & Dahlan, U. A. (2021). Students' Perceptions Toward The Use of Kahoot! Online Game for Learning English Corresponding Email Article's History Students' Perceptions Toward the Use of Kahoot! Online Game for Learning English. *Ethical Lingua*, *8*(1), 2021.

Lopes, A. P., Babo, L., Azevedo, J. M., & Torres, C. (2017, March). *Data analysis and learning analytics for measure effects of gamification in a math online project* [Conference paper]. INTED2017: 11th International Technology, Education and Development Conference, Valencia, Spain. https://doi.org/10.21125/inted.2017.1896

Lopez, C. E., & Tucker, C. S. (2024, February 6). *Implementing gamification in engineering bridge programs: A case study exploring the use of the Kahoot! application*. https://doi.org/10.18260/1-2-1153-33757

Lowther, D. L., Inan, F. A., Daniel Strahl, J., & Ross, S. M. (2008). Does technology integration "work" when key barriers are removed? *Educational Media International*, *45*(3), 195–213. https://doi.org/10.1080/09523980802284317

Lüking, S., Wünsche, S., & Wilde, M. (2023). The effect of basic psychological needs on the flow experience in a digital gamified learning setting. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1256350

Maarouf, H. (2019). Pragmatism as a Supportive Paradigm for the Mixed Research Approach: Conceptualizing the Ontological, Epistemological, and Axiological Stances of Pragmatism. *International Business Research*, *12*(9), 1. https://doi.org/10.5539/ibr.v12n9p1

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The Role of Mathematics in interdisciplinary STEM education. *ZDM - Mathematics Education*, *51*(6), 869–884. https://doi.org/10.1007/s11858-019-01100-5

Makaremi, N., Yildirim, S., Morgan, G. T., Touchie, M. F., Jakubiec, J. A., & Robinson, J. B. (2024). Impact of classroom environment on student wellbeing in higher education: Review and future directions. In *Building and Environment* (Vol. 265). Elsevier Ltd. https://doi.org/10.1016/j.buildenv.2024.111958

Manzano-León, A., Rodríguez-Ferrer, J. M., Aguilar-Parra, J. M., & Salavera, C. (2023). The Legends of Elendor: Educational Gamification as an Influential Factor in Academic Flow and Academic Performance in Socially Depressed Communities. *Education Sciences*, *13*(1). https://doi.org/10.3390/educsci13010008

Marie, J., Ilustre, M., & Raqueño, A. R. (2020). Development and Evaluation of Game-Based Learning System for Differential Calculus. *International Journal of Advance Study and Research Work*, *3*, 33. https://doi.org/10.5281/zenodo.3776061

Masanja, V. G. (2002). *Mathematics and other disciplines: The Impact of Modern Mathematics in other Disciplines*. https://eric.ed.gov/?id=ED472050

Mavroudi, A., Almeida, T., Frennert, S., Laaksolahti, J., & Viberg, O. (2022). A card game for designing activities for technology-enhanced learning in higher education. *Education and Information Technologies*, *27*(2), 2367–2383. https://doi.org/10.1007/s10639-021-10668-z

Maxwell, J. A., & Mittapalli, K. (2010). *Realism as a Stance for Mixed Methods Research*. In A. Tashakkori, & C. Teddlie, (2010). SAGE handbook of mixed methods in social and behavioral research (2 ed., pp145-168). SAGE. https://doi.org/10.4135/9781506335193.n6

Mdlalose, N., Ramaila, S., & Ramnarain, U. (2021). Using Kahoot! As A Formative Assessment Tool in Science Teacher Education. *International Journal of Higher Education*, *11*(2), 43. https://doi.org/10.5430/ijhe.v11n2p43

Meletiou-Mavrotheris, M., & Prodromou, T. (2016). Pre-Service Teacher Training on Game-Enhanced Mathematics Teaching and Learning. *Technology, Knowledge and Learning*, *21*(3), 379–399. https://doi.org/10.1007/s10758-016-9275-y

Mercer, J. (2007). The challenges of insider research in educational institutions: wielding a double-edged sword and resolving delicate dilemmas. *Oxford Review of Education*, *33*(1), 1–17. https://doi.org/10.1080/03054980601094651

Morgan, D. L. (2007). Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. *Journal of Mixed Methods Research*, *1*(1), 48–76. https://doi.org/10.1177/2345678906292462

Mulenga, E. M., & Marbán, J. M. (2020). Is covid-19 the gateway for digital learning in mathematics education? *Contemporary Educational Technology*, *12*(2), 1–11. https://doi.org/10.30935/cedtech/7949

Nadezhda, M., & Okello, P. (2010). Learning and Teaching College Algebra at University level: Challenges and Opportunities: A Case Study of USIU. In *Technology & Entrepreneurship in Africa* (Vol. 2, Issue 1).

Neville, R., Shipman, P. D., Levinger, N. E., & Krummel, A. T. (2018). ConfChem Conference on Mathematics in Undergraduate Chemistry Instruction: Applied Mathematics for Chemistry Majors. *Journal of Chemical Education*, *95*(8), 1438–1439. https://doi.org/10.1021/acs.jchemed.8b00107

Nurul Hasana, S. (2018). Multimedia Development Using Visual Basic for Application (VBA) to Improve Students' Learning Motivation in Studying Mathematics of Economics. *Indonesian Journal of Mathematics Education*, *1*(1).

Ortiz, M., Chiluiza, K., & Valcke, M. (2016). Gamification in higher education and STEM: A systematic review of literature. EDULEARN16 Proceedings (pp. 6548-6558). IATED. https://doi.org/10.21125/edulearn.2016.0422

Ortiz, W., Castillo, D., & Wong, L. (2022). Mobile Application: A Serious Game Based in Gamification for Learning Mathematics in High School Students. *Conference of Open Innovation Association, FRUCT*, *2022-April*, 220–228. https://doi.org/10.23919/FRUCT54823.2022.9770917

Öztuna, D., Halil Elhan, A., & Tüccar, E. (2006). Investigation of Four Different Normality Tests in Terms of Type 1 Error Rate and Power under Different Distributions. *Turkish Journal of Medical Sciences, 36(*3), 171-176. https://journals.tubitak.gov.tr/medical/vol36/iss3/7/

Parvaiz, G. S., Mufti, O., & Wahab, M. (2016). Pragmatism for mixed method research at higher education level. *Business & Economic Review, 8*(2), 67–79. https://doi.org/10.22547/BER/8.2.5

Pedersen, J. B., Andersen, A. S. Ö., & Majgaard, G. (2012). Design of trigonometry apps for vocational education. *Proceedings of the IASTED International Conference on Human-Computer Interaction, HCI 2012*, 226–232. https://doi.org/10.2316/P.2012.772-020

Perera, H., Hewagamage, K. P., & Weerasinghe, T. A. (2017). Game based learning as a supplementary approach in teaching mathematics. *17th International Conference on Advances in ICT for Emerging Regions, ICTer 2017 - Proceedings*, *2018-January*, 287–293. https://doi.org/10.1109/ICTER.2017.8257799

Perttula, A., Kiili, K., Lindstedt, A., & Tuomi, P. (2017). Flow experience in game based learning – a systematic literature review. *International Journal of Serious Games*, *4*(1). https://doi.org/10.17083/ijsg.v4i1.151

Petros, A., Weber, R., Broadway, S., Ford, R., Powell, C., Hunter, K., Williamson, V., Walker, D., Mamiya, B., Pilar, J. Del, Shelton, G. R., & Mason, D. (2018). *MUST-Know Pilot Study*. http://bit.ly/1HyamPc

Powell, C. B., Simpson, J., Williamson, V. M., Dubrovskiy, A., Walker, D. R., Jang, B., Shelton, G. R., & Mason, D. (2020). Impact of arithmetic automaticity on students' success in second-semester general chemistry. *Chemistry Education Research and Practice*, *21*(4), 1028–1041. https://doi.org/10.1039/d0rp00006j

Prieto, M. C., Palma, L. O., Tobías, P. J. B., & León, F. J. M. (2019). Student assessment of the use of kahoot in the learning process of science and mathematics. *Education Sciences*, *9*(1). https://doi.org/10.3390/educsci9010055

Proulx, J. N., & Romero, M. (2016). Game and learning mechanics under the perspective of self-determination theory for supporting motivation in digital game based learning. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *9599*, 141–150. https://doi.org/10.1007/978-3-319-40216-1_15

Qian, M., & Clark, K. R. (2016). Game-based Learning and 21st century skills: A review of recent research. *Computers in Human Behavior*, *63*, 50–58. https://doi.org/10.1016/j.chb.2016.05.023

Rashid, T., & Asghar, H. M. (2016). Technology use, self-directed learning, student engagement and academic performance: Examining the interrelations. *Computers in Human Behavior*, *63*, 604–612. https://doi.org/10.1016/j.chb.2016.05.084

Rondina, J. Q., & Roble, D. B. (2019). Game-based design mathematics activities and students' learning gains. *The Turkish Online Journal of Design Art and Communication*, *9*(1), 1–7. https://doi.org/10.7456/10901100/001

Rosillo, N., & Montes, N. (2021). Escape room dual mode approach to teach maths during the covid-19 era. *Mathematics*, *9*(20). https://doi.org/10.3390/math9202602

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology*, *25*(1), 54–67. https://doi.org/10.1006/ceps.1999.1020

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, *61*. https://doi.org/10.1016/j.cedpsych.2020.101860

Saha, M., Islam, S., Akhi, A. A., & Saha, G. (2024). Factors affecting success and failure in higher education mathematics: Students' and teachers' perspectives. *Heliyon*, *10*(7). https://doi.org/10.1016/j.heliyon.2024.e29173

Sandrone, S., & Carlson, C. (2021). Gamification and game-based education in neurology and neuroscience: Applications, challenges, and opportunities. *Brain Disorders*, *1*, 100008. https://doi.org/10.1016/j.dscb.2021.100008

Schwartz, N., Click, K., & Bartel, A. (2022). *Educational Psychology: Learning and Instruction* (pp. 1–35). https://doi.org/10.1007/978-3-030-26248-8_67-1

Segun, O., & Oluwaseyi, S. (2020). *Impact of Teachers' Instructional Practices On Students' Achievement and Self-Efficacy in Mathematics Commonwealth Journal of Academic Research (CJAR.EU)*. https://doi.org/10.5281/zenodo.3879417

Setiawan, A. (2020). Kahoot-Based Learning Game to Improve Mathematics Learning Motivation of Elementary School Students. *Jurnal Pendidikan Matematika*, *11*(1), 39–48. http://ejournal.radenintan.ac.id/index.php/al-jabar/index

Shabihi, N., Taghiyareh, F., & Abdoli, M. H. (2016). *2016 8th International Symposium on Telecommunications (IST)*. IEEE.

Shaker, A. J., Hurst, P. S., & Marshall, E. M. (2021). The effect of Kahoot on undergraduate student anxiety and confidence when studying statistics. *MSOR Connections*, *19*(2). https://doi.org/10.21100/msor.v19i2.1245

Shelton, G. R., Villalta-Cerdas, A., Jang, B., Dubrovskiy, A., Mamiya, B., Weber, R., Broadway, S., Williamson, V., Powell, C., & Mason, D. (2023). Importance of Academic Legacy on Student Success in First- and Second-Semester General Chemistry. *Journal of Research in Science, Mathematics and Technology Education*, 121–148. https://doi.org/10.31756/jrsmte.631

Shernoff, D. J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. S. (2003). Student Engagement in High School Classrooms from the Perspective of Flow Theory. In *School Psychology Quarterly* (Vol. 18, Issue 2).

Sianturi, A. D., & Hung, R. T. (2022). The Challenges of Using Kahoot! in Teaching and Learning in Higher Education – A Systematic Review. *ACM International Conference Proceeding Series*, 72–77. https://doi.org/10.1145/3568739.3568753

Siew, P. H. (2018). Pedagogical Change in Mathematics Learning: Harnessing the Power of Digital Game-Based Learning. *Journal of Educational Technology & Society*, *21*(4), 259–276. http://www.jstor.org/stable/26511553

Silva, B. D. da, Lencastre, J. A., Bento, M., & Osório, A. J. (Eds.) (2019). *Experiences and perceptions of pedagogical practices with Game-Based Learning & Gamification*. University of Minho, Portugal. https://www.researchgate.net/publication/359904347_Experiences_and_perceptions_of_pedagogical_practices_with_Game-Based_Learning_Gamification

Siraj-Ud-Doulah, Md. (2021). An Alternative Measures of Moments Skewness Kurtosis and JB Test of Normality. *Journal of Statistical Theory and Applications*, *20*(2), 219. https://doi.org/10.2991/jsta.d.210525.002

Sonsona, D. A., Talidong, K. J. B., & Toquero, C. M. D. (2021). Game-based learning: Reinforcing a paradigm transition on pedagogy amid COVID-19 to complement emergency online education. *International Journal of Didactical Studies*, *2*(2), 10458–10458. https://doi.org/10.33902/ijods.2021269730

Spencer, H. E. (1996). Mathematical SAT Test Scores and College Chemistry Grades. In *Journal of Chemical Education* • (Vol. 73, Issue 12). https://pubs.acs.org/sharingguidelines

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction*, *28*. https://doi.org/10.1016/j.lcsi.2020.100457

Suparlan, A., Shohaimay, F., Haron, N. F., Abidin, S. Z., Dasman, A., & Mokhtar, M. (2019). Evaluation of students' perceptions of game-based mathematics classroom using fuzzy conjoint analysis. In *gading Journal for Science and Technology* (Vol. 2, Issue 2).

Taherdoost, H. (2016). Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. In *International Journal of Academic Research in Management (IJARM)* (Vol. 5, Issue 2). https://ssrn.com/abstract=3205035

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. In *International journal of medical education* (Vol. 2, pp. 53–55). https://doi.org/10.5116/ijme.4dfb.8dfd

Economics and statistics office. (2024). *The Cayman Islands compendium of statistics 2023*. https://www.eso.ky/storage/right_page_docums/uploadFilePdf/417/The%20Cayman%20Islands%20Compendium%20of%20Statistics%202023.pdf

Thurmond, V. A. (2001). The point of triangulation. *Journal of Nursing Scholarship*, *33*(3), 253–258. https://doi.org/10.1111/j.1547-5069.2001.00253.x

Ting, F. S. T., Lam, W. H., & Shroff, R. H. (2019). Active learning via problem-based collaborative games in a large mathematics university course in Hong Kong. *Education Sciences*, *9*(3). https://doi.org/10.3390/educsci9030172

Tobon, S., Ruiz-Alba, J. L., & García-Madariaga, J. (2020). Gamification and online consumer decisions: Is the game over? *Decision Support Systems*, *128*. https://doi.org/10.1016/j.dss.2019.113167

Toda, A. M., Valle, P. H. D., & Isotani, S. (2018). The dark side of gamification: An overview of negative effects of gamification in education. *Communications in Computer and Information Science*, *832*, 143–156. https://doi.org/10.1007/978-3-319-97934-2_9

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87–102. https://doi.org/10.1007/s10798-011-9160-x

Tu, W. M., Liu, Y., & Ruvalcaba Diaz, S. (2024). Academic motivation and contextual influences in well-being for students with disabilities in higher education. *Journal of American College Health*. https://doi.org/10.1080/07448481.2024.2404932

Tufail, I., & Mahmood, M. K. (2020). Teaching Methods Preferred by School Science Teachers and Students in their Classroom. *PUPIL: International Journal of Teaching, Education, and Learning*, *4*(2), 332–347. https://doi.org/10.20319/pijtel.2020.42.332347

Tyack, A., & Mekler, E. D. (2020). Self-Determination Theory in HCI Games Research: Current Uses and Open Questions. *Conference on Human Factors in Computing Systems - Proceedings*, *2020-January*. https://doi.org/10.1145/3313831.3376723

Wahyuni, S., & Etfita, F. (2023). The application of Kahoot as an online assessment tool to foster student's engagement: Student's experiences and voices. *Register Journal*, *16*(2), 248–266. https://doi.org/10.18326/rgt.v16i2.248-266

Walker, C. T. R. (2022). Wellbeing in higher education: a student perspective. *Pastoral Care in Education*, *40*(3), 310–320. https://doi.org/10.1080/02643944.2022.2093963

Wang, A. I., & Tahir, R. (2020). The effect of using Kahoot! for learning – A literature review. *Computers and Education*, *149*. https://doi.org/10.1016/j.compedu.2020.103818

Wang, C. K. J., & Demerin, P. A. G. (2023). Relationship between self-determination theory and flow in the domain of sports and academics among student-athletes. *Asian Journal of Sport and Exercise Psychology*, *3*(2), 114–120. https://doi.org/10.1016/j.ajsep.2023.08.003

Wang, S. L., Zhang, A. Y., Messer, S., Wiesner, A., & Pearl, D. K. (2021). Student-Developed Shiny Applications for Teaching Statistics. *Journal of Statistics and Data Science Education*, *29*(3), 218–227. https://doi.org/10.1080/26939169.2021.1995545

Wati, I. F., & Yuniawatika (2020). Digital Game-Based Learning as A Solution to Fun Learning Challenges During the Covid-19 Pandemic. In *Proceedings of the 1st International Conference on Information Technology and Education (ICITE 2020)*. https://doi.org/10.2991/assehr.k.201214.237

White, A. L., Way, J., Perry, B., & Southwell, B. (2005). *Mathematical Attitudes, Beliefs and Achievement in Primary Pre-service Mathematics Teacher Education*. Mathematics Teacher Education and Development, 7, 33-52. https://mted.merga.net.au/index.php/mted/article/view/94/71

Wiemker, M., Elumir, E., & Clare, A. (2015). *Escape Room Games: "Can you transform an unpleasant situation into a pleasant one?"* http://scottnicholson.com/pubs/erfacwhite.pdf

Wiggins, B. E. (2016). An overview and study on the use of games, simulations, and gamification in higher education. *International Journal of Game-Based Learning*, *6*(1), 18–29. https://doi.org/10.4018/IJGBL.2016010102

Williams, D. P., Lo Fan Hin, S., & Erlina, E. (2019). First-Year Undergraduate Student Expectations of two UK Chemistry Degree Programmes. *New Directions in the Teaching of Physical Sciences*, *14*. https://doi.org/10.29311/ndtps.v0i14.3047

Williamson, V. M., Walker, D. R., Chuu, E., Broadway, S., Mamiya, B., Powell, C. B., Shelton, G. R., Weber, R., Dabney, A. R., & Mason, D. (2020). Impact of basic arithmetic skills on success in first-semester general chemistry. *Chemistry Education Research and Practice*, *21*(1), 51–61. https://doi.org/10.1039/c9rp00077a

Willis, W. K., Williamson, V. M., Chuu, E., & Dabney, A. R. (2022). The Relationship Between a Student's Success in First-Semester General Chemistry and Their Mathematics Fluency, Profile, and Performance on Common Questions. *Journal of Science Education and Technology*, *31*(1). https://doi.org/10.1007/s10956-021-09927-y

Wulanningtyas, M. E., Davit, Y., Putra, P., Triani, N. N., & Andriyati, N. (2021). Android Snake Ladder on Triangle using TGT Learning Model to Increase Learning Motivation. *Journal of Mathematical Society*, *3*. https://doi.org/10.18326/hipotenusa.v3i2.6295

Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research,* 39(1), pp. 93–112. https://doi.org/10.1177/0739456X17723971

Yağmur, B. E. (2020). A game-based activity related to prime numbers. *Journal of Inquiry Based Activities, 10(*1) 18-30. https://files.eric.ed.gov/fulltext/EJ1265707.pdf

Yeasmin, M. (2017). Mathematics is everywhere – Connecting with other disciplines. *International Journal of Applied Research, 3*(6), 750-751. https://www.allresearchjournal.com/archives/2017/vol3issue6/PartK/3-6-162-600.pdf

Yeh, C. Y. C., Cheng, H. N. H., Chen, Z. H., Liao, C. C. Y., & Chan, T. W. (2019). Enhancing achievement and interest in mathematics learning through Math-Island. *Research and Practice in Technology Enhanced Learning*, *14*(1). https://doi.org/10.1186/s41039-019-0100-9

Yunus, E., & Zaibon, S. B. (2021). Connecting Computational Thinking (CT) Concept with the Game-Based Learning (GBL) Elements. *International Journal of Interactive Mobile Technologies*, *15*(20), 50–67. https://doi.org/10.3991/ijim.v15i20.23739

Zabala-Vargas, S., García-Mora, L., Arciniegas-Hernández, E., Reina-Medrano, J., de Benito-Crosetti, B., & Darder-Mésquida, A. (2021). Strengthening Motivation in the Mathematical Engineering Teaching Processes – A Proposal from Gamification and Game-Based Learning. *International Journal of Emerging Technologies in Learning*, *16*(6), 4–19. https://doi.org/10.3991/ijet.v16i06.16163

Zainuddin, Z. (2018). Students' learning performance and perceived motivation in gamified flipped-class instruction. *Computers and Education*, *126*, 75–88. https://doi.org/10.1016/j.compedu.2018.07.003

Appendix A: Questionnaire

This questionnaire relates to your experience of the game-based learning intervention that took place in your classroom during the past few weeks. Your feedback can help us understand the impact of the intervention on your learning experience. Your responses are anonymous and confidential. Press the arrow below to complete the questionnaire. Think about your experience of playing the algebra mathematics games. Please answer the following questions.

5-point Likert scale - (1) Strongly Disagree; (2) Disagree; (3) Neither Agree nor Disagree; (4) Agree; (5) Strongly Agree.

Autonomy

		1	2	3	4	5
1	I was free to decide how I wanted to play the games.					
2	I could approach the games in my own way.					
3	The games allowed me to play how I wanted to.					
4	I had important decisions to make while playing.					
5	The choices I made during gameplay influenced what happened.					
6	My actions had an impact on the games.					

Competence

		1	2	3	4	5
1	With time, I became better at playing the mathematics games.					
2	My math (game playing) abilities have improved since the beginning.					
3	My mastery of the mathematics games improved with practice.					
4	I was good at playing the games.					
5	I felt competent at playing the games.					
6	I felt capable and effective when playing the games.					

Relatedness

		1	2	3	4	5
1	I really like the people I play with.					
2	Other players are friendly towards me					
3	What other players did in the game had an impact on my actions.					
4	I had to adapt my actions to other players' actions.					
5	I was paying attention to other players' actions.					

Flow

		1	2	3	4	5
1	I felt challenged while playing the game.					
2	My thoughts ran smoothly and fluently while playing the game.					
3	I did not notice time passing while playing the game.					
4	I had no problem concentrating while playing the game.					
5	My mind was completely clear while playing the game.					
6	I was totally immersed in gameplay.					
7	Thoughts occurred automatically, inspired by what I was playing in the game.					
8	I knew what I had to do each step of the way.					
9	I gained a good understanding of the mathematics content the game tried to teach me.					
10	During gameplay, I became completely lost in thought to the point where I was unaware of myself.					
11	I enjoyed learning mathematics by playing games.					
12	The games were interesting.					

Game Element Motivation

		1	2	3	4	5
1	The reward system of points and leaderboard motivated me to complete the tasks associated with the course.					
2	The reward system of points and leaderboard motivated me to maintain a high level of performance.					
3	The reward system of points and leaderboard motivated me to progress and get better.					
4	I was motivated by the competitive element of leaderboards.					
5	I worked harder because I wanted to be at the top of the leaderboard.					
6	Getting instant feedback was positive for my overall learning.					
7	The reward system of points and leaderboard motivated me because I was working with others.					

Open-ended Questions

1. Did you enjoy using games to learn mathematics? If yes, what made it enjoyable?
2. Are there any benefits to using games to learn mathematics? What are they?
3. Are there any challenges to using games to learn mathematics? What are they?
4. Would you recommend that math games be included in math/chemistry lessons? Why or why not?
5. Do you have any other comments relating to your experience of using game-based learning in the classroom?

Demographics

1. What is your gender identity?
2. How old are you?
3. What is the course code for the course in which you did the mathematics game-based intervention?

Appendix B: Focus Group Questions

1. How did the game-based intervention impact your abilities in the chemistry course?
2. What were some of the challenges that you had with the game-based intervention?
3. Did you get a good understanding of the mathematics that the games were trying to teach you?
4. Are there any benefits in your opinion to using games to learn mathematics?