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Game-Based Learning, Algebra Achievement, and Student Engagement: A Mixed-Methods Study in Secondary Education

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ABSTRACT

Game-based learning (GBL) has emerged as a transformative pedagogical strategy that fosters student engagement, motivation, and cognitive development. A mixed-methods approach was employed, involving classroom interventions, student feedback surveys, and academic performance data from a select group of secondary school learners. The findings reveal that game-based educational practices not only enhance conceptual understanding but also improve problem-solving skills, collaboration, and sustained interest in learning. The study positions GBL as a sustainable instructional model that can be effectively integrated into mainstream curricula, especially in contexts requiring inclusive and engaging pedagogies. By aligning digital innovations with sustainable education frameworks, this research contributes to the discourse on policy and practice transformation in secondary education.

Keywords: Game-based learning, GBL, Secondary Education, Algebra Achievement, SDG 4, Educational Innovation

INTRODUCTION

Where Pedagogical Innovation and Global Numeracy Mandates Collide

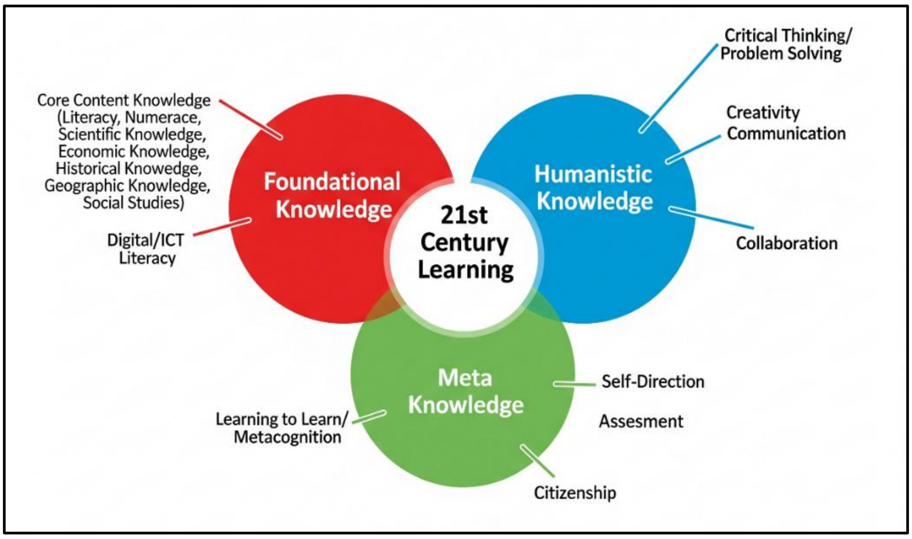

Figure 1: 21st Century Learning: A Holistic Framework

High school education around the world is at a crossroads. Traditional teaching methods in arithmetic that focus on rote memory, passive learning, and standardized instruction are having a harder and harder time keeping students interested and helping them acquire the complex analytical skills they will need in the twenty-first century. Reaching Sustainable Development Goal 4 (SDG 4), which calls for everyone to have access to high-quality, inclusive education by 2030, is taking longer and is not going as smoothly as it should be. Current trends indicate that the international community risks failing to achieve this critical objective without significant and systemic intervention.

If nothing more is done, roughly 84 million kids and teens are expected to stay out of school, and about 300 million students won't have the basic reading and math abilities they need to do well (UNESCO Institute for Statistics, 2022; UNESCO, 2021). This harsh truth shows that there is a big gap between providing education and providing meaningful learning. It shows that we need new teaching methods that can get students interested again and produce high-quality, fair results, especially in core subjects like math. According to data from around the world, a shocking number of teenagers in school are not meeting the minimum proficiency levels in math, which is necessary for future employment and being an active global citizen. This is a crisis of proficiency, not just access (UNESCO, 2022).

In this case, Game-Based Learning (GBL) is a strong and scientifically backed way to teach. GBL is an active learning method that uses the built-in game mechanics and structures, like rules, goals, conflict, and interactive feedback loops on purpose to get students more involved and help them learn in certain ways (Plass, Homer, & Kinzer, 2015). It is not just for fun; it is a planned learning experience based on well-known educational theories. Community, cultural context, and interactive tools are essential elements of cognitive development and learning. Sociocultural learning theories, particularly those formulated by Vygotsky, provide a robust framework for understanding the efficacy of game-based learning (GBL) (Vygotsky, 1978). GBL promotes the cultivation of critical thinking, problem-solving skills, and sustained motivation, alongside content mastery, by situating learning within an immersive, interactive, and often collaborative context (Qian & Clark, 2016).

For math teachers, this pedagogical approach provides a wide range of tools. For example, number sense and critical thinking can be developed through logic puzzles like Mathdoku, and procedural fluency can be developed through entertaining, low-stress games like Math Bingo. Also, geometry puzzle games can help kids learn how to think critically about space, and some algebraic equation games can help kids understand how to employ abstract ideas in real life (Ke, 2008; Kiili, 2005).

The goal's clear calls for "inclusive and equitable quality education" and the advancement of "lifelong learning opportunities for all" are highly compatible with GBL's capabilities (United Nations, 2015; United Nations, 2024). A neurodiverse range of learners can benefit from more accessible and engaging learning experiences created by well-designed GBL environments, which offer flexible pathways to understanding that may not be available through traditional instruction (Vasalou, Khaled, Holmes, & Gooch, 2017). GBL directly addresses the need to give teenagers the skills they will need for future employment and active global citizenship by promoting abilities like teamwork, critical analysis, and adaptability (Dede, 2010). This is in line with the larger goal of sustainable development.

Despite GBL's great potential, a notable "implementation paradox" still exists. Games have historically had difficulty breaking into the formal secondary education in a systematic manner, despite the fact that a growing body of literature demonstrates their potential (Clark, Tanner-Smith, & Killingsworth, 2016; Perrotta, Featherstone, Aston, & Houghton, 2013). A large portion of the empirical research that is currently available is limited to short-term interventions and frequently measures discrete outcomes without relating them to the more comprehensive, systemic objectives stated in global development frameworks such as SDG 4 (Wouters & van Oostendorp, 2013). This important research gap is directly addressed in this study. It goes beyond merely determining whether GBL is effective in mathematics to look into how it works in a secondary school classroom in the real world and how its various effects fit with the particular goals of SDG 4. GBL is a core pedagogical strategy that can address the proficiency crisis by promoting the deep cognitive skills, like hypothesis testing, logical deduction, and strategic problem-solving that underlie true mathematical understanding, according to this research, rather than as a supplementary engagement tool.

In order to accomplish this, the current study uses a convergent parallel mixed-methods design to investigate the effects of a long-term GBL intervention on secondary school students' algebra learning in a comprehensive manner (Creswell & Plano Clark, 2018). This study offers a triangulated and nuanced analysis by combining rich qualitative data on student experiences and perceptions with quantitative data on academic performance and skill development. The main goal is to produce solid evidence that can guide educational policy and pedagogical practice, establishing GBL as a long-term teaching model that can revolutionize secondary mathematics education. A thorough review of the literature on GBL in mathematics and its relationship to SDG 4 is the first step in this paper's structure, which then explains the research methodology in detail, presents and analyzes the integrated findings in detail, and concludes with a discussion of the implications for practice, policy, and future research.

LITERATURE REVIEW

Situating GBL within Mathematical, Educational, and Developmental Frameworks

The theoretical underpinnings and empirical data pertaining to game-based learning are summarized in this review, which places it in the framework of secondary mathematics education and the SDG 4 global mandate for high-quality education. It looks at the fundamentals of GBL, the effects it has been shown to have on math learners, the specific goals of SDG 4 that pertain to numeracy, and how GBL might be used to promote educational equity in a subject that frequently causes anxiety in students.

The Architecture of Game-Based Learning: Principles and Pedagogy

It is crucial to define GBL precisely and investigate its theoretical foundations in order to appreciate its transformative potential. GBL is a teaching approach that aims to engage students by directly integrating learning concepts or instructional content into games (Plass, Homer, & Kinzer, 2015). It is not the same as "gamification," which is a related but different idea. Gamification is the process of adding game-like elements, like points, badges, and leaderboards, to already-existing, non-gaming activities in order to boost motivation and engagement, whereas GBL transforms the learning process itself into a game (Deterding, Dixon, Khaled, & Nacke, 2011). In gamification, the rewards are frequently external to the learning task, whereas in GBL, the learning is inherent to the gameplay (Landers, 2014).

Any game's structure can be broken down into a few key elements: players, distinct goals, resources, rules, conflict, boundaries, and unpredictable outcomes that provide motivation (Salen & Zimmerman, 2004). Games are effective learning tools because of the skillful balancing of these components. In order to achieve a worthwhile objective, they establish a controlled setting where students can experiment, take chances, and learn from mistakes.

GBL's pedagogical efficacy is grounded in established learning theories. Sociocultural theories, particularly those of Lev Vygotsky, underscore the significance of social interaction and cultural resources in cognitive development (Vygotsky, 1978). Vygotsky's concept of the "zone of proximal development" (ZPD) is especially relevant to teaching math. The ZPD is the space between what a student can do on their own and what they can do with help. For example, a well-designed digital algebra game can provide tasks that are appropriate for the learner's ZPD and help them improve by giving them tips that change dependent on how well they do on the problems.

GBL supports sociocultural theories as well as experiential learning theory and constructivism (Kiili, 2005). Constructivism posits that students actively generate their own knowledge through experiences (Piaget, 1972). Games exemplify this approach by providing interactive environments that necessitate experimentation and exploration by pupils. Similarly, David Kolb's theory of experiential learning emphasizes a cycle of action and reflection that is inherent in gaming (Kolb, 1984). When a student tries to solve a Mathdoku puzzle, they go through this cycle: they put in a number (concrete experience), see that it makes a logical contradiction with other clues (reflective observation), re-evaluate their strategy based on the rules of the puzzle (abstract conceptualization), and try a new number combination (active experimentation). This process of testing and improving hypotheses again and over again is at the heart of mathematical thinking.

Empirical Evidence on GBL's Impact on Secondary School Mathematics Learners

Many studies have looked into how GBL affects teens who are learning math, and they have all found the same thing in a few critical areas, such as motivation and engagement, the growth of cognitive skills, and the lessening of negative feelings like arithmetic anxiety.

One of the most common benefits of GBL is that it greatly increases students' interest and drive in arithmetic, which is a subject that many students find hard or boring. Studies indicate that when GBL is properly executed, student engagement levels routinely surpass those associated with traditional instruction (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke, & Edwards, 2016; Jarvela, 2015; Veermans, & Leinonen, 2015). This higher level of involvement isn't only because it's new; it's also because of how the game is designed, like giving players choices, rapid feedback, and the chance to work together. GBL makes math practice more fascinating and dynamic, which helps students engage with the material on a deeper level. This is important for understanding topics that need to be practiced and thought about all the time.

There is strong proof that GBL makes people better at math in a way that is statistically significant. GBL helps students understand abstract arithmetic concepts by connecting them to real-world actions and visual representations in the gaming world. This strategy can help students learn how to tackle a wide range of issues by connecting what they already know to the abstract nature of math. This works especially well for math topics like algebra, where playing digital games can help pupils understand concepts better and solve problems better (Vankus, 2021).

GBL has been found to greatly improve higher-order cognitive skills that are necessary for teaching arithmetic in the 21st century. Games may get kids really into tackling hard, multi-faceted problems, which is not the case with problems in textbooks that are not related to real life. The process of navigating an in-game challenge, coming up with and testing ideas, and changing techniques based on feedback is thought to help with both learning knowledge and building strong problem-solving skills (Kim, Park, & Baek, 2009). This active, inquiry-based method encourages the basic parts of mathematical reasoning, such as logical, critical, creative, and analytical thinking (Qian & Clark, 2016).

One key benefit of GBL in math is that it can help kids who are afraid of arithmetic, which is a big emotional barrier to learning for many of them. Mathematics is often seen as the "least-liked core subject" since many think it is hard and can make them anxious. This worry creates a negative feedback loop that makes people avoid arithmetic tasks and not care about them because they are afraid of failing. GBL can interrupt this pattern by creating an interactive, low-stakes, and often "fun" learning environment where mistakes are seen as a natural part of the discovery process instead of a sign of failure (De Freitas, 2018). This makes for a stress-free learning environment where students may learn at their own pace without worrying about anything. GBL can help students get over their performance anxiety and become intrinsically motivated to beat the game's challenge by putting math practice within an interesting gaming story or puzzle (Habgood & Ainsworth, 2011; Deci & Ryan, 2000). In this way, GBL is more than simply a way to get students interested; it is a way to break down a big emotional barrier. This remediation facilitates cognitive advancements by creating the necessary psychological conditions for students to re-engage with the subject matter. Research indicates that educational games can assist students in reevaluating their self-perceptions of their capabilities and mitigate emotions associated with arithmetic fear (Ketelhut, 2007).

A Taxonomy of Game-Based Learning Approaches in Secondary Mathematics

To go beyond a single view of "GBL," it helps to group different game types based on the math skills they are meant to teach (Shute & Ke, 2012). This gives teachers a good way to choose the appropriate tool for a certain learning goal.

This includes games meant for practicing basic abilities over and over again. Two examples are Math Snakes & Ladders and Math Bingo. These games are great for getting better at solving one-step equations, fractions, decimals, and other math problems. The fast-paced, competitive nature of bingo keeps all of the pupils interested at the same time, turning what could be a monotonous drill into a fun group exercise. Players must solve a math problem to move forward in Snakes and Ladders, which is based on chance. This makes it a great way to practice for warm-ups or review sessions without any stress.

Along with math abilities, these games also demand pupils to use their number sense and deductive reasoning. The best example is Mathdoku, which is also known as KenKen. Students have to fill in a grid with numbers while following two rules: the numbers inside the heavily outlined "cages" must add up to a target number using a set procedure, and no number can be used more than once in any row or column (like Sudoku). Mathdoku is different from rote repetition because it makes students think creatively about how numbers are related and how to combine them (for example, "What three numbers in a 6x6 grid add up to 7?"). This helps them improve their ability to reason and solve problems in math.

The major purpose of this group is to help people learn how to manipulate and visualize mental objects. Games like Tangrams, Pentominoes, and Soma Cubes are great for enhancing spatial reasoning skills including mental rotation, 2D and 3D visualization, and spatial planning. These skills are important for doing well in geometry and other STEM topics. By moving these real or digital puzzle pieces about, students can get a better, more intuitive knowledge of geometric transformations (translation, rotation, reflection), area, and perimeter.

This broad category includes a number of forms that are meant to make abstract algebraic ideas more real and important. Some examples are digital escape rooms, mazes with algebraic equations, and narrative-based games like "Quadratic Rush." These games help children understand algebra by making them solve an equation or find the appropriate way through a maze to "unlock a door" in an escape room.They develop conceptual understanding beyond simple procedural memorization by transforming algebraic procedures from a collection of abstract rules to be memorized into a useful tool for accomplishing a specific objective.

The following table summarizes this taxonomy, offering a practical guide for educators.

Table 2.1: A Taxonomy of Game-Based Learning Approaches in Secondary Mathematics

Game Category	**Example Games**	**Primary Mathematical Skills Targeted**	**Classroom Application & Rationale**
Procedural Fluency	Math Bingo, Math Snakes and Ladders	Arithmetic operations, fact fluency, fractions, decimals, solving simple equations.	Warm-ups, review sessions, reinforcement of foundational concepts in a low-stress, high-repetition format.
Logical Reasoning	Mathdoku (KenKen)	Number sense, deductive logic, arithmetic operations, problem-solving stamina.	Weekly challenges, early-finisher activities, developing flexible thinking about number relationships.
Spatial Reasoning	Tangrams, Pentominoes, Soma Cubes	Mental rotation, 2D/3D visualization, spatial planning, geometric properties.	Introduction to geometry units, hands-on exploration of transformations, area, and perimeter.
Algebraic Thinking	Equation Mazes, Digital Escape Rooms, "Quadratic Rush"	Solving multi-step equations, understanding variables, applying algebraic concepts.	Core instructional activity for introducing or practicing abstract algebraic concepts in a motivating, contextualized environment.

Forging a Path to Equity: GBL as an Inclusive Tool in the Mathematics Classroom

To meet SDG 4's goal of "inclusive and equitable" education, we need to critically look at how new teaching methods like GBL can help all students, especially in math. GBL could change the way things are done in traditional classrooms, where speed and rote memorization are often the only signs of success. GBL offers students a lot of different ways to show what they know and build their confidence (Vasalou, Khaled, Holmes,

& Gooch, 2017). For example, a student who has trouble with timed math tests might be very good at the strategic, visual problem-solving needed to play a geometry puzzle game like Pentominoes.

This has a direct effect on the problem of math anxiety. GBL promotes equity for students who have historically been marginalized or discouraged by conventional math instruction by cultivating a more engaging, stimulating, and less intimidating educational atmosphere (Richard & Gray, 2018). Collaborative elements in many games can also make the classroom a better place to learn, where students learn to rely on each other and work together to create knowledge instead of competing with each other. The potential of GBL as an inclusive tool relies on intentional design that incorporates cultural relevance, diverse representation, and accessibility for neurodiverse learners (Benton, Vasalou, Khaled, & Gooch, 2017; Holmes et al., 2022).It is crucial to know that GBL is not fair by nature. Also, any GBL plan must take digital equity into account to make sure that all students have the tools and help they need (Warschauer, 2004).

Research Design and Intervention

The thorough research design and methodological techniques used in this study are described in this section. The research objectives and hypotheses are explained, the convergent parallel mixed-methods design was justified, the participant cohort and the mathematics-focused GBL intervention are described, the data collection tools and procedures are specified, and the analytical approach for combining the quantitative and qualitative data is presented.

Research Objectives and Hypotheses

The main goal of this study is to look into how a GBL intervention affects secondary school students' learning of arithmetic in many ways and how these effects fit within the framework of SDG 4. To direct this investigation, the subsequent study objectives and associated hypotheses were established:

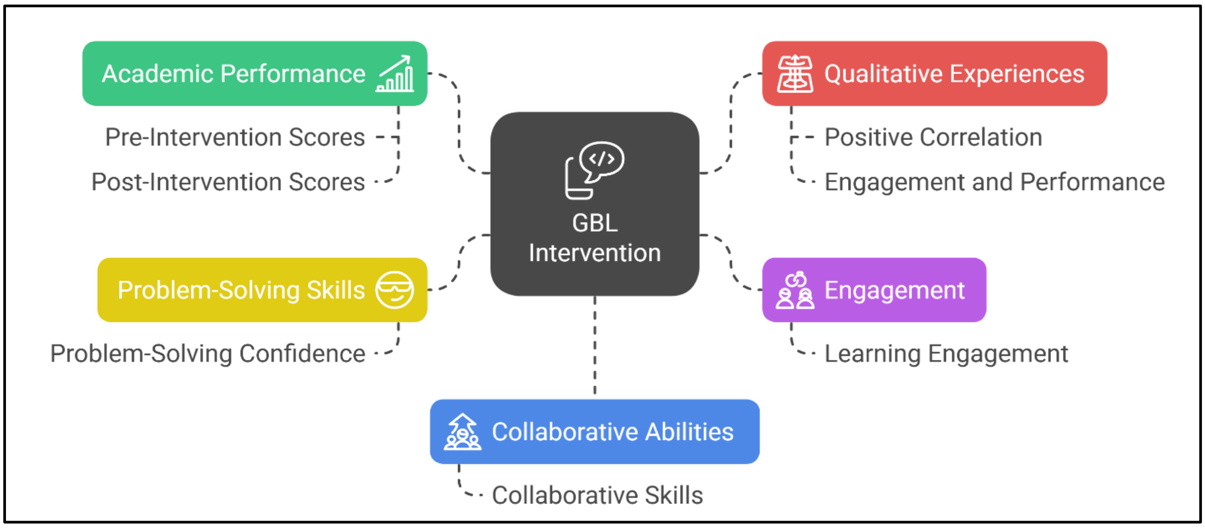

Figure 2: Research Objectives and Hypotheses

Objective 1: To assess the influence of a GBL intervention on the academic performance of secondary school students in Algebra. This goal is strongly related to SDG 4 Target 4.1, which stresses the importance of getting good results in fundamental courses like arithmetic.

Hypothesis 1 (H1): Students engaged in the GBL intervention will exhibit a statistically significant enhancement in academic performance, as indicated by the comparison of pre- and post-intervention algebra test results.

Objective 2: To evaluate the impact of the GBL intervention on students' self-reported engagement, problem-solving capabilities, and collaboration skills within a mathematics framework. These talents are very important for the overall goals of excellent education and the growth of skills needed in the 21st century.

Hypothesis 2 (H2): Students will exhibit statistically significant enhancements in (a) learning engagement, (b) problem-solving confidence, and (c) collaborative abilities subsequent to their involvement in the GBL intervention.

Objective 3: To investigate students' qualitative experiences and views of the GBL environment for learning mathematics, pinpointing variables that enhance or impede its efficacy.

Hypothesis 3 (H3): A positive association will exist between students' involvement level in the GBL intervention and their academic performance improvements, indicating that engagement is a crucial mechanism by which GBL facilitates mathematical learning.

A Convergent Parallel Mixed-Methods Inquiry

This study employs a convergent parallel mixed-methods approach to achieve a thorough and dependable comprehension of the influence of GBL (Creswell & Plano Clark, 2018). This methodology is particularly appropriate for this research as it facilitates the concurrent gathering and analysis of both quantitative and qualitative data, yielding a more comprehensive representation than each method could provide independently (Dawadi, Shrestha, & Giri, 2021). The quantitative strand, which includes survey measures and statistics on academic performance, tries to address the "what" and "how much" questions. For example, how much did involvement go up, and how did that affect performance on the algebra test?

Exploring the "why" and "how" for example, why did students feel more engaged while learning algebra, and how did they experience collaboration within the games is the goal of the concurrent qualitative strand, which consists of open-ended survey responses.

The process entails gathering both quantitative and qualitative data at the same time, but initially analyzing them separately. When the two sets of findings are combined to find areas of complementarity, divergence, and convergence, the design's strength becomes apparent during the last interpretation stage. The pragmatist research paradigm, which emphasizes the application of techniques that best answer the research questions, is consistent with this strategy (Creswell & Plano Clark, 2018).

Participant Cohort and Intervention Context

The study was conducted with a cohort of 150 students from two intact Grade 9 mathematics classes at a public secondary school in a diverse urban area. The sample was selected using convenience sampling. The total sample consisted of 78 male students (52%) and 72 female students (48%), with an average age of 14.6 years (SD=0.5). Prior to the intervention, all participants and their legal guardians provided informed consent.

The intervention was implemented over a six-week instructional unit focused on Algebra I, specifically on solving linear equations. In place of traditional lecture-based instruction and textbook assignments, students engaged with a curated suite of GBL activities based on the taxonomy developed in the literature review. The intervention was structured as follows:

Throughout the six-week unit on linear equations, different game-based activities were used to make learning more engaging, interactive, and enjoyable for students. During the first two weeks, students played a digital Algebraic Equation Maze, where solving each one- or two-step equation correctly helped them move forward in the maze. This allowed students to practise the concepts while receiving immediate feedback and working at their own pace. In Weeks 3 and 4, students worked in small groups on a Digital Escape Room. They had to solve a series of multi-step equations with variables on both sides to unlock clues and solve the final mystery. This activity encouraged students to discuss their ideas, help one another, and work together to find solutions. Mathdoku puzzles were also used as short weekly warm-up activities throughout the unit to help students develop logical thinking, number sense, and confidence in solving problems. At the end of the unit, a whole-class Math Bingo game was used to review the concepts before the post-test. Students solved different types of linear equations and looked for the correct answers on their bingo cards. Overall, these activities made the mathematics classroom more lively and enjoyable while giving students opportunities to practise concepts, learn from their peers, and build confidence in problem-solving. During the intervention, the classroom teacher's role transitioned from that of a traditional instructor to a facilitator. The teacher provided initial guidance, monitored group progress, posed probing questions to stimulate critical thinking, and provided scaffolding when teams encountered significant obstacles, a role consistent with best practices for facilitating GBL (Shute & Ke, 2012; Kapp, 2017).

Data Collection Instruments and Procedures

To understand the impact of the six-week intervention from different perspectives, data were collected using a combination of academic assessments and student feedback. Data were gathered at two stages—before the intervention began (pre-test) and immediately after it ended (post-test). This helped in comparing students' performance and perceptions before and after participating in the game-based learning activities.

Academic Performance Data: To assess changes in students' understanding of algebra concepts (Objective 1), a 40-item multiple-choice Algebra Concepts Test was administered before and after the intervention. The test focused on important concepts related to solving linear equations and was aligned with the Grade 9 mathematics curriculum. The test was developed with the involvement of the participating teacher and was reviewed by two experienced mathematics educators to ensure that the questions were appropriate and relevant to the learning objectives.

Student Feedback Survey: A student survey was also conducted through an online platform to understand how students experienced the intervention and whether they felt it helped improve their engagement, problem-solving, and collaborative skills (Objectives 2 and 3). The survey instrument, adapted from the original study, is included in Appendix A. It included several sections. Part A collected basic demographic information such as students' age and gender. Part B focused on learning engagement and included 18 adapted items from the validated Interpreting Learning Engagement Scale (ILES), which draws on the behavioral, emotional, cognitive, and agentic dimensions of engagement established in prior research (Fredricks, Blumenfeld, & Paris, 2004; Reschly & Christenson, 2022). Students responded to statements related to behavioral, emotional, cognitive, and agentic engagement using a five-point Likert scale. Part C measured students' perceptions of their problem-solving skills through 15 items covering areas such as defining problems, considering different alternatives, and making decisions. Part D focused on collaborative skills and included 12 items related to positive interdependence, social interaction, teamwork, and conflict resolution. These sections used a five-point Likert scale to allow students to express the extent to which they agreed with each statement.

Finally, Part E, which was included only in the post-intervention survey, consisted of four open-ended questions. These questions gave students an opportunity to describe their experiences in their own words, including what they enjoyed, what they found challenging, and how the game-based activities influenced the way they participated and learned mathematics. This qualitative feedback provided additional insight into the students' experiences and helped complement the quantitative findings.

Analytical Strategy for Data Integration

A multi-stage analytical strategy was employed to examine the quantitative and qualitative data independently before integrating the findings to develop a comprehensive interpretation of the effects of the game-based learning (GBL) intervention. The quantitative analysis focused on changes in students' academic performance and self-reported learning outcomes, while the qualitative analysis explored students' experiences and perceptions of the intervention. The findings from both strands were subsequently integrated to provide a more comprehensive understanding of the intervention outcomes.

All quantitative data were analyzed using IBM SPSS Statistics Version 28. Prior to analysis, the dataset was screened for completeness and accuracy, and descriptive statistics, including means and standard deviations, were calculated for the study variables. The internal consistency of the adapted survey instruments was examined using Cronbach's alpha coefficients, with a value of 0.70 or above considered indicative of acceptable reliability.

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To examine the hypotheses, paired-samples t-tests were conducted to compare students' pre-intervention and post-intervention scores. These analyses were used to determine whether statistically significant changes occurred in academic performance, learning engagement, problem-solving skills, and collaborative skills following the GBL intervention. To test H3, Pearson's product-moment correlation coefficient was calculated to examine the association between changes in students' learning engagement and changes in their academic performance. Gain scores were calculated by subtracting each student's pre-intervention score from their corresponding post-intervention score. Statistical significance was evaluated using the predetermined significance level of $p < .05$.

Responses to the open-ended survey questions were analyzed using an inductive thematic analysis approach based on the six-phase framework proposed by Braun and Clarke (2006). The analysis involved: (1) familiarizing the researchers with the data, (2) generating initial codes, (3) searching for potential themes, (4) reviewing and refining the themes, (5) defining and naming the final themes, and (6) producing the written analysis. The qualitative responses were examined systematically to identify recurring patterns, experiences, perceptions, and meanings associated with students' participation in the GBL intervention. Selected student responses were used as illustrative quotations to support and contextualize the identified themes.

Mixed-Methods Integration. Following the independent analysis of the quantitative and qualitative datasets, the findings were integrated using a joint display. The joint display presented key quantitative results alongside corresponding qualitative themes and illustrative student responses. This approach facilitated direct comparison and interpretation of findings across the two strands of the study. Integrating the quantitative and qualitative evidence enabled a more nuanced understanding of the effects of the GBL intervention on students' mathematics learning, engagement, problem-solving, and collaborative experiences. The integration also helped identify areas of convergence and complementarity between the numerical outcomes and students' reported experiences.

Presentation and Analysis of Findings

The quantitative data were examined to evaluate the impact of the mathematics GBL intervention on students' academic performance, engagement, problem-solving skills, and collaborative competencies. The study included 150 Grade 9 students. A summary of the participant demographics is provided in Table 1. The sample was relatively balanced in terms of gender.

Table 1: Participant Demographics

Characteristic	Value
Total Participants (N)	150
Age (Mean, SD)	14.6 (0.5) years
Gender	
Male (n, %)	78 (52.0%)
Female (n, %)	72 (48.0%)

Cronbach's alpha coefficients were calculated for the composite scales. All scales demonstrated good to excellent internal consistency: Learning Engagement ($\alpha_{pre}=.88, \alpha_{post}=.91$), Problem-Solving Skills ($\alpha_{pre}=.85, \alpha_{post}=.89$), and Collaborative Skills ($\alpha_{pre}=.82, \alpha_{post}=.87$). These strong reliability coefficients indicate that the items within each scale consistently measured the same underlying construct. Table 2 presents the means and standard deviations for all dependent variables before and after the GBL intervention. A clear pattern of improvement is visible across all measures.

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Table 2: Descriptive Statistics for Pre- and Post-Intervention Measures

Variable	**Pre-Intervention**	**Post-Intervention**
	M (SD)	**M (SD)**
Academic Performance in Algebra (out of 40)	18.75 (5.21)	29.43 (4.88)
Learning Engagement (Scale 1-5)	2.98 (0.72)	4.25 (0.58)
Problem-Solving Skills (Scale 1-5)	3.11 (0.69)	4.02 (0.61)
Collaborative Skills (Scale 1-5)	3.25 (0.74)	4.18 (0.66)
Note. M = Mean; SD = Standard Deviation.		

Hypothesis Testing Results: Inferential statistical tests were conducted to determine if the observed changes were statistically significant. The results are summarized in Table 3.

Hypothesis 1 (Academic Performance): The paired-samples t-test revealed a statistically significant increase in academic performance scores in algebra from pre-intervention (M=18.75) to post-intervention (M=29.43), $t(149)=18.92, p<.001$. The magnitude of this effect was large (Cohen's d=1.54). Therefore, H1 was supported, aligning with research showing GBL significantly enhances academic performance in mathematics (Clark, Tanner-Smith, & Killingsworth, 2016; Vankus, 2021).

Hypothesis 2 (Skills and Engagement**):** The paired-samples t-tests showed statistically significant increases for all three self-reported measures. Learning Engagement increased significantly ($t(149)=16.54, p<.001$), Problem-Solving Skills increased significantly ($t(149)=13.01, p<.001$), and Collaborative Skills increased significantly ($t(149)=12.67, p<.001$). All effects were large. These results provide strong support for H2.

Hypothesis 3 (Correlation): A Pearson's correlation coefficient was computed to assess the relationship between the gain in learning engagement and the gain in academic performance. There was a strong, positive correlation between the two variables, $r(148)=.61, p<.001$. This indicates that students who experienced a greater increase in engagement also tended to experience a greater increase in their academic performance, thus supporting H3.

Table 3: Results of Paired-Samples T-Tests and Correlation Analysis

Hypothesis Test	**Mean Difference**	**t-statistic**	**df**	**p-value**	**Cohen's d**
H1: Academic Performance	10.68	18.92	149	<.001	1.54
H2a: Learning Engagement	1.27	16.54	149	<.001	1.35
H2b: Problem-Solving Skills	0.91	13.01	149	<.001	1.06
H2c: Collaborative Skills	0.93	12.67	149	<.001	1.03
H3: Correlation Analysis	**r**		**df**	**p-value**	
Engagement Gain & Academic Gain	.61		148	<.001	
Note. All p-values are two-tailed.					

The thematic analysis of the 150 students' open-ended responses yielded four major themes that provide rich, contextual detail about their experiences with the GBL intervention for learning mathematics.

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Theme 1: Making Abstract Algebra Concrete: The idea that the games made abstract algebraic concepts relevant and understandable was a recurring theme. Students often explained how they were able to understand the purpose of the mathematical procedures by using algebra to solve a concrete problem in a game, such as figuring out the correct path in a maze or unlocking a clue in an escape room. "I never understood why we needed to'solve for x'. It was merely a set of rules to commit to memory. However, in order to obtain the code for the subsequent lock in the escape room, we had to solve the equation. At last, it became clear that algebra is a useful tool for problem-solving. (Participant #67) "The best game was the maze one. Instant feedback was when you saw that the correct response took you forward and the incorrect one led you to a dead end. Instead of merely speculating, it forced me to consider the steps. (Participant #103)

Theme 2: Low-Stakes Practice and Reduced Fear of Failure: Students frequently emphasized how beneficial the GBL environment is as a place where they can practice and make mistakes without worrying about grades right away. This theme provides compelling evidence for GBL's ability to reduce math anxiety. The enjoyment of taking on a challenge replaced the fear of making a mistake. "When the teacher calls on me in math class, I usually get really anxious. However, the games only involved attempting to solve the puzzle. It didn't matter if you got it wrong; you simply tried a different approach. Compared to a worksheet, it was far less stressful. (Participant #34)
"I enjoyed your ability to make mistakes. If you make a mistake on a typical test, that's it. If your first attempt didn't work in the game, you simply had to go back and figure out what went wrong. You learned how to proofread your own work from it. (Participant #81)

Theme 3: Collaborative Sense-Making: The quantitative rise in collaborative skills was closely reflected in the qualitative data. During the Digital Escape Room exercise, students gave thorough explanations of how they collaborated, outlining negotiation, shared sense-making, and group decision-making processes. Positive interdependence was necessary for the game's design in order to promote communication and a sense of shared accountability. "The extremely challenging equations required collaboration from our group. We would all check the solution after one person read the problem and another wrote it out. We both caught a lot of each other's errors. Without teamwork, we would not have been able to complete it." (Participant #122) "Seeing how various members of my group approached the issues was interesting. My teammate would sometimes see something I missed, even if my idea didn't work out. In the end, we taught one another. (Participant #59)

Theme 4: Game Rules vs. Math Rules: Although the majority of the responses were positive, the analysis also found a theme about difficulties. Some students said they had trouble at first telling the difference between the mathematical concepts and the game's mechanics. This emphasizes how important teacher facilitation is to maintaining the clarity of the learning objectives. "At first, I was more concerned with attempting to 'beat the game' than with the math. It took some time to realize that doing the math right was the only way to win. We needed several reminders from the teacher to slow down and consider the steps. (Participant #28.) It was occasionally difficult to determine whether we were stuck because the math was challenging or because we were not understanding the game's instructions. Before asking the teacher for assistance, we became frustrated a few times. (Participant #96)

Integrated Analysis: A Triangulated Perspective

A strong, multi-layered understanding of the effects of the GBL intervention is provided by the integration of the quantitative and qualitative data. Strong convergence and greater explanatory power are revealed by the methodical comparison of the two datasets in Table 4's joint display. Theme 1, "Making Abstract Algebra Concrete," effectively contextualizes the statistically significant improvement in algebra performance (H1). Students' descriptions of using algebra as a useful tool in the game world, which makes it easier to transfer knowledge from abstract rules to contextualized application, account for the numerical increase in test scores. The improvement in test scores can be explained by this process of applying mathematical knowledge in a meaningful context, which is a hallmark of deep, conceptual learning.

Similarly, Themes 2, "Low-Stakes Practice and Reduced Fear of Failure," and 3, "Collaborative Sense-Making," vividly illustrate the noteworthy increases in self-reported engagement and collaborative skills (H2). According to the qualitative data, the GBL environment established the social structures (required teamwork) and affective conditions (reduced anxiety) that allowed students to interact deeply with the content and one another.

Important subtleties are also revealed by the integration. The qualitative Theme 4, "Game Rules vs. Math Rules," offers a crucial counterpoint to the quantitative data, which indicates a generally positive effect. It implies that careful pedagogical scaffolding is necessary for GBL to be effective in order to keep students' attention on the learning goals. The development of useful recommendations for teachers wishing to implement GBL in the math classroom depends on this integrated finding.

Table 4: Joint Display of Integrated Quantitative and Qualitative Findings

Research Objective	**Quantitative Results (Summary)**	**Qualitative Themes**	**Illustrative Quotes**	**Integrated Inference**
Obj. 1: Academic Performance	Statistically significant increase in algebra concept test scores (p<.001, large effect size).	Theme 1: Making Abstract Algebra Concrete	"It finally clicked that algebra is a tool you can actually *use* to figure things out." (P #67)	The improvement in academic performance is strongly linked to the GBL environment's ability to make abstract mathematical concepts functional and meaningful, facilitating conceptual transfer and deeper understanding.
Obj. 2: Engagement	Statistically significant increase in self-reported Learning Engagement (p<.001, large effect size).	Theme 2: Low-Stakes Practice and Reduced Fear of Failure	"It was way less stressful than a worksheet." (P #34)	The GBL intervention created a highly motivating and less anxiety-inducing learning environment. The low-stakes, challenge-oriented format fostered intrinsic motivation, driving sustained student interest and participation.
Obj. 2: Problem-Solving	Statistically significant increase in self-reported Problem-Solving Skills (p<.001, large effect size).	Theme 2: Low-Stakes Practice and Reduced Fear of Failure	"If your first try didn't work, you just had to go back and find your error. It taught you how to check your own work." (P #81)	The game provided a safe environment for students to practice and develop core problem-solving competencies, such as learning from errors and iterative thinking, leading to increased confidence in these skills.
Obj. 2: Collaboration	Statistically significant increase in self-reported Collaborative Skills (p<.001, large effect size).	Theme 3: Collaborative Sense-Making	"We caught so many of each other's mistakes. We couldn't have finished it if we didn't work as a team." (P #122)	The game's design successfully fostered positive interdependence, requiring students to engage in authentic collaborative behaviors like communication, peer-checking, and negotiation to achieve shared goals.
Obj. 3: Student Experience	Strong positive correlation between engagement gain and	Theme 4: Game Rules vs. Math Rules	"It took a while to realize that the only way to win was to actually do	While highly effective overall, the student experience can be hampered if the game's mechanics overshadow the learning objectives. This

	academic gain (r =.61,p<.001).		the math correctly." (P #28)	highlights that the success of GBL depends on careful implementation and active teacher facilitation to keep students focused on the mathematical principles.

DISCUSSION

The results of this study offer strong, multifaceted proof of the effectiveness of game-based learning as a revolutionary teaching method in the teaching of secondary mathematics. In addition to discussing the study's limitations, this section interprets the significance of the findings, relates them directly to the global mandate of Sustainable Development Goal 4, and examines the practical and policy implications for incorporating GBL into regular educational practice.

The findings of this mixed-methods investigation support and add to the corpus of existing research on GBL in mathematics. Many earlier studies have demonstrated the beneficial effects of GBL on cognitive and affective outcomes, and the statistically significant and large-effect-size gains in academic performance, learning engagement, problem-solving skills, and collaborative abilities are consistent with these findings (Clark, Tanner-Smith, & Killingsworth, 2016; Wouters & van Oostendorp, 2013; Abdul Jabbar & Felicia, 2015). The integration of the quantitative and qualitative data, however, is what really makes this study significant because it offers a deeper comprehension of the mechanisms underlying these beneficial changes. It is evident from the quantitative data that GBL is effective. Both algebraic content knowledge and critical 21st-century skills improved significantly as a result of the intervention. The idea that engaged students are learning students is empirically supported by the notable strong positive correlation between increased engagement and academic achievement (H3), particularly in a subject like mathematics where perseverance is crucial.

The qualitative results elucidate the process of this change. The integrated analysis shows two main ways that things work. The first is the way that math anxiety is lessened. Students' stories show that they feel very empowered and relieved in the GBL setting. The intervention directly targeted a fundamental emotional obstacle to mathematics success by creating a low-stakes environment that embraces errors as an inherent aspect of the learning process (Theme 2) (De Freitas, 2018). The second mechanism, conceptual transfer, appears to necessitate this reduction in anxiety. Students talked about how using abstract algebraic rules to solve problems in the game made them useful tools (Theme 1). The game makes an abstract process into a useful idea by acting as a cognitive bridge (Kolb, 1984). This is what deep, conceptual learning is all about, and it explains why grades have gone up so much. The detailed descriptions of teamwork (Theme 3) also show that collaborative GBL is more than just group work; it is a structured setting that requires real communication, compromise, and shared responsibility (Sica, Delli Veneri, & Miglino, 2011; Jarvela, 2015; Veermans, & Leinonen, 2015). The game's design made social interaction a key way to learn, and teamwork was really important.

However, the results also caution against an overly optimistic view of GBL. Theme 4 ("Game Rules vs. Math Rules") is an important reminder that games and technology are just tools, not the answer to everything (Kimmons & Johnstun, 2019). For GBL to work, the teacher must carefully and actively implement it so that the main goal is still to learn math (Wouters & van Oostendorp, 2013).

Even though this study's conclusions are solid, it's vital to recognize its limitations. First, the results' generalizability is restricted by the use of a convenience sample drawn from a single school. Second, the intervention only lasted six weeks; to find out if the gains are maintained over time, longitudinal research is required. Third, the high levels of engagement might have been a result of the GBL intervention's novelty (a possible Hawthorne effect). Despite these limitations, the study offers significant practical and policy implications

CONCLUSION AND FUTURE DIRECTIONS

This study has provided a comprehensive and nuanced analysis of GBL's impact by integrating detailed qualitative student experiences with robust quantitative data through a convergent parallel mixed-methods design. The results clearly show that students' academic performance in algebra, learning engagement, problem-solving skills, and collaborative abilities can all be improved statistically and practically with a well-designed, multifaceted GBL intervention. The qualitative analysis showed that these gains were driven by an immersive, motivating, and experiential learning process that made abstract concepts concrete and lessened the fear of failure often associated with mathematics. The quantitative results showed large effect sizes across all measured domains. A strong, triangulated confirmation of GBL's capacity to promote the very abilities and results that are central to high-quality mathematics education is offered by the combination of these two data streams. It makes the case that GBL provides a tried-and-true approach to re-engage students and develop the sophisticated skills required for the twenty-first century (Dede, 2010; Qian & Clark, 2016), at a time when conventional approaches are failing to bridge the numeracy proficiency gap.

Based on these conclusions, the following recommendations are proposed:

For Educators and School Leaders: Establishing professional learning communities centered on GBL in mathematics is advised for educational institutions. These communities can work together to create frameworks for assessing and choosing a variety of mathematical games, exchange best practices for facilitation, and foster an environment that encourages pedagogical experimentation.

For Game Developers: Closer cooperation between classroom practitioners and the educational technology sector is desperately needed. To make games that are not only entertaining but also pedagogically sound, culturally relevant, and easily incorporated into school curricula, developers should collaborate with educators and a variety of student populations.

The results of this study should be expanded upon in a number of important ways in future research. To monitor the long-term effects of GBL on students' arithmetic performance, retention of skills, and attitudes toward STEM fields and careers, longitudinal research is required. Teachers would benefit greatly from comparative studies that methodically examine the disparate impacts of different game genres (such as digital versus non-digital, competitive versus collaborative). The impact of GBL on marginalized and vulnerable student populations, including students with specific math learning disabilities like dyscalculia, must be the primary focus of future research in order to fully realize the promise of GBL as a tool for inclusive and equitable quality education for all (Benton, Vasalou, Khaled, & Gooch, 2017; Vasalou, Khaled, Holmes, & Gooch, 2017). The research community can continue to develop the body of evidence required to overhaul our educational systems and guarantee that every student is prepared to succeed in the complex world of the future by following these lines of investigation.

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