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Enhancing Mathematics Achievement: A Game-Based Learning Intervention in Qatar

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Abstract

Background/purpose. This study investigated the impact of the Test Survey for Students (TSFS) software, a game-based learning intervention (GBL), on the mathematical achievement and attitudes of Qatari fourth-grade students.

Materials/methods. Utilizing a mixed-methods approach guided by the Theory of Planned Behavior (TPB) and the TPACK framework, the study examined the effects of a three-month intervention focusing on algebraic concepts related to angles.

Results. Quantitative data, collected through pre- and post-intervention surveys and achievement tests, revealed statistically significant improvements in both students' attitudes towards mathematics and their performance on algebra-related tasks. Qualitative data, gathered through classroom observations, student and teacher interviews, provided rich contextual insights into the intervention's impact, supporting the quantitative findings and highlighting the importance of teacher expertise and adequate technological infrastructure in successful GBL implementation.

Conclusion. The findings demonstrate the potential of well-designed game-based learning interventions to enhance mathematics learning, while also emphasizing the need for ongoing professional development and support for educators.

1. Introduction

Decades of research consistently reveal suboptimal mathematics achievement among students worldwide, particularly concerning fundamental concepts and problem-solving abilities (OECD, 2022). This persistent underachievement has driven educators to explore innovative pedagogical approaches aimed at enhancing student engagement and learning outcomes. Game-based learning (GBL) has emerged as a promising strategy (Hamari et al., 2014; Nacke & Deterding, 2017). However, the inconsistent definition and implementation of GBL in educational settings necessitate further clarification (Faiella & Ricciardi, 2015; Gündüz & Akkoyunlu, 2019; Nacke & Deterding, 2017). Unlike merely using games for rewards or distractions, GBL, as defined by Nicolaidou (2022), Kapp 2012, and Gee 2024), strategically integrates game mechanics—challenges, rewards, feedback loops—to create engaging and immersive learning environments. This approach leverages the motivational power of games to foster active learning, provide immediate feedback, and encourage sustained engagement, ultimately improving comprehension and mastery (Garris, Ahlers, & Driskell, 2002). Gamification, while related, differs from GBL; it integrates game-like elements to enhance experiences within non-game contexts (Deterding et al., 2011), unlike GBL, which focuses on developing original educational games and software (Glover, 2013). Furthermore, even negative feedback in GBL is often viewed constructively, fostering growth (Glover, 2013; Faiella & Ricciardi, 2015). The immediate and comprehensive feedback inherent in GBL is particularly beneficial (Hamari et al., 2014; Nacke & Deterding, 2017). Despite the potential of GBL, effective implementation requires meticulous planning and integration within existing educational frameworks (Buckley, P., & Doyle, E., 2014; Bicen & Kocakoyun, 2018).

Previous studies have demonstrated significant positive effects of game-based learning (GBL) in mathematics education. Research has shown that GBL positively impacts several dimensions of learning, with the most substantial effects on learning performance (33%), followed by engagement (21%), knowledge level (17%), and motivation (13%) (Juhari & Abu Bakar, 2020). The motivational aspects of GBL have been attributed to six key game characteristics: fantasy, rules/goals, sensory stimuli, challenge, mystery, and control (Hartmann & Gommer, 2019). When properly designed, educational games create a flow experience where students become fully immersed in learning activities, leading to improved outcomes (Benini & Thomas, 2021). Furthermore, GBL has been shown to positively affect students' cognitive and behavioral engagement through the strategic use of game mechanics such as points, badges, and leaderboards (Juhari & Abu Bakar, 2020). However, research has also indicated that the effectiveness of GBL varies considerably based on implementation context, pedagogical approach, and alignment with specific learning objectives (Naujanienė et al., 2021). Despite these promising findings, there remains a notable gap in the literature regarding culturally specific applications of GBL, particularly in Middle Eastern educational contexts, and studies employing established theoretical frameworks to understand the mechanisms of GBL effectiveness in mathematics education (Hartmann & Gommer, 2019).

1.1. Research gap

While prior research has established the general effectiveness of game-based learning (GBL) in mathematics education, there is a lack of studies examining its long-term impact on student attitudes and achievement in Middle Eastern contexts, particularly using established theoretical frameworks such as the Theory of Planned Behavior. This study addresses this gap by evaluating the TSFS software among Qatari middle school students, providing new insights into the sustained effects of GBL and informing culturally relevant educational practices.

This study investigates the efficacy of the Test Survey for Students (TSFS) software in teaching algebraic concepts to Qatari middle school students. Utilizing the Theory of Planned Behavior (TPB) framework (Ajzen, 1991), this research examines the impact of TSFS on students’ attitudes toward mathematics, their achievement, and their behavioral intentions regarding game-based learning. The main aim is to assess the effectiveness of TSFS in improving both learning outcomes and attitudes toward mathematics. Specifically, the objectives are:

2. To evaluate the impact of TSFS on students' mathematics achievement.
3. To examine changes in students' attitudes toward mathematics after using TSFS.
4. To assess students' behavioral intentions regarding future engagement with game-based learning.
5. To provide practical recommendations for classroom implementation and inform the design of future GBL tools.

1.2. Research Aim

The aim of this study is to evaluate the effectiveness of the Test Survey for Students (TSFS) software, a game-based learning intervention, in enhancing algebraic achievement and shaping attitudes toward mathematics among Qatari middle school students. The study is guided by the Theory of Planned Behavior (TPB) and the TPACK framework to understand both student and teacher factors influencing the outcomes.

1.2. Research Questions

1. To what extent does the use of TSFS influence students' attitudes toward mathematics and their beliefs about game-based learning, as conceptualized by the TPB components of attitude, subjective norms, and perceived behavioral control?

2. To what extent does the use of TSFS improve students' achievement in algebra, considering students' prior mathematical abilities and the role of teachers' technological pedagogical content knowledge (TPACK) in mediating these outcomes?

2. Literature Review

2.1. Game-Based Learning in Mathematics

While the integration of technology in education is widely acknowledged, the specific application of game-based learning (GBL) in mathematics requires nuanced examination. Although the shift towards active and student-centered learning models is well-documented (Chang et al., 2015), the pedagogical implications of GBL remain a subject of ongoing investigation. While the motivational power of games is often cited as a key benefit (Garris, Ahlers, & Driskell, 2002), the effectiveness of GBL hinges on careful design and implementation, moving beyond simply using games as rewards or distractions (Devlin, 2011; Denham, 2019).

Several studies have explored the diverse approaches to GBL in mathematics education. Mobile learning, utilizing readily accessible digital devices, offers significant potential for flexible and personalized learning (Dabbagh et al., 2016). However, the success of GBL is intrinsically linked to the alignment of game mechanics with pedagogical objectives and content knowledge (Buckley & Doyle, 2014; Bicen & Kocakoyun, 2018). The focus should extend beyond mere entertainment to encompass the effective integration of game elements into a comprehensive learning framework that supports skill acquisition and conceptual understanding (Gee, 2024; Prensky, 2021; Nicolaidou et al., 2022).

The use of games to address challenges in learning mathematical language has received specific attention. McGuffey (2015 highlights the difficulties students face when encountering unfamiliar mathematical notation and terminology, arguing that GBL can make abstract concepts more accessible by presenting them within engaging and interactive contexts. Swinyard's 2012 work on guided reinvention underscores the value of allowing students to actively construct their own

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understanding of mathematical concepts through game-based activities. This active construction fosters deeper learning and addresses the limitations of traditional methods that rely heavily on rote memorization and passive reception of information. Adaptable game designs, where teachers can modify game parameters to align with specific learning objectives, are particularly beneficial (Author et al., 2023).

The effectiveness of GBL in improving mathematical achievement has been examined in numerous studies, with results generally indicating positive outcomes (Kebritchi, Pan, Hirumi, & Bai, 2010; Bahr & Rieth, 1989; Conati & Zhao, 2009; Ke & Grabowski, 2007; Kebritchi, Hirumi, & Bai, 2010). These studies often demonstrate improved student engagement, increased motivation, and enhanced problem-solving skills. However, the reported outcomes are sometimes inconsistent across studies, potentially because of methodological differences or differences in the types of games employed. Some research also highlights the importance of considering the specific cognitive skills targeted by the game and the need for careful integration of GBL with other pedagogical approaches (Clark, Tanner-Smith, & Killingsworth, 2016; Denham, 2022). The abstract nature of mathematics often poses unique challenges in designing engaging games, necessitating careful consideration of the visual representation of concepts and the use of appropriate game mechanics to enhance understanding (Bai, Pan, Hirumi, & Kebritchi, 2012; Heckenberg, Herbert, & Webber, 2004; Rhyne, 2000). The use of visualizations and interactive elements can improve comprehension and engagement, particularly for students who struggle with abstract mathematical concepts (Tokac, Novak, & Thomson, 2018; Chang et al., 2015).

Despite the growing body of evidence supporting the benefits of GBL, several critical issues require further investigation. The lack of standardized assessment tools tailored to the unique characteristics of GBL environments presents a major challenge in evaluating learning outcomes (Naccache, 2025; Ghamrawi, 2023; Kouatli et al., 2022). The effectiveness of GBL is also affected by factors such as teacher training, technological infrastructure, and the alignment of the game with learning objectives and curriculum standards (Author et al., 2023). Further research is needed to address these issues and establish evidence-based practices for integrating GBL effectively into mathematics education.

2.2. TSFS (teaching software for students)

This study utilized a novel game-based learning software, Test Survey for Students (TSFS), designed to enhance middle school students' understanding of internal and external angles. TSFS, a web and mobile application, presents a game where students guide a rocket through space, advancing only by correctly solving problems involving angle calculations. This game-based approach integrates interactive elements, fostering active learning and promoting engagement with typically challenging mathematical concepts. The software's design is grounded in the Theory of Planned Behavior (TPB) framework (Ajzen, 1991), incorporating elements to foster positive attitudes toward mathematics and build self-efficacy.

TSFS incorporates several key features to enhance the learning experience: (a) an intuitive interface that promotes exploration and discovery, (b) a system of immediate feedback and tailored hints that support self-directed learning, (c) a collaborative learning component enabling peer interaction and knowledge sharing, and (d) an AI-powered chatbot providing personalized support and addressing student misconceptions. The visual design, employing a calming color scheme (Babin, 2013) while integrating bright elements to highlight key information (Ajlouni et al,2025; Tetteh & Ashong, 2018), contributes to a positive learning environment. Teacher oversight is facilitated via a web portal displaying student progress and identifying areas where further support may be needed. TSFS's adaptive learning path adjusts to individual student needs, ensuring personalized support and maximizing learning outcomes, ultimately aiming to foster mathematical mastery and long-term success. Prior to this study, TSFS was successfully implemented in teaching Arabic skills within a STEAM context (Author et al., 2023).

Figure 1. The Game Window

2.3. Theoretical framework: the theory of planned behavior, TPACK

This section will outline the theoretical frameworks guiding this research: the Theory of Planned Behavior (TPB) and Technological Pedagogical Content Knowledge (TPACK). The TPB (Ajzen, 1991) posits that behavioral intention is the strongest predictor of actual behavior, shaped by three key factors: attitudes toward the behavior, subjective norms (perceived social pressure), and perceived behavioral control (self-efficacy) (Figure). This study operationalizes the TPB by examining students' attitudes toward using games for learning mathematics, their perception of social norms related to game-based learning, and their self-efficacy in using the TSFS software. These factors were assessed through a combination of pre- and post-intervention surveys and qualitative interviews to ascertain the impact on students' behavioral intentions and their actual use of the TSFS software.

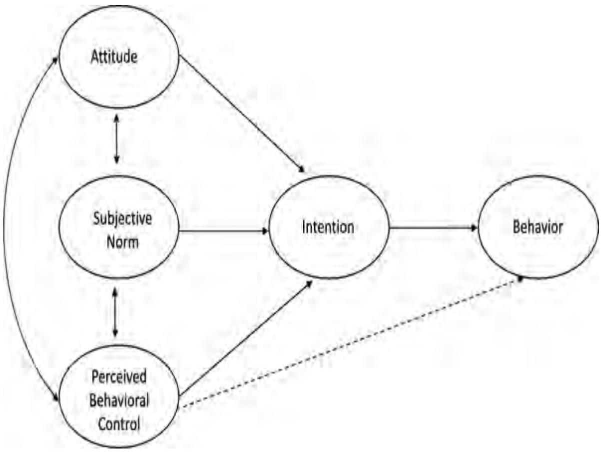

Figure 2. Theory of Planned Behavior

Attitudes: The overall evaluation of whether a behavior is positive or negative (based on prior behavioral contingencies). Subjective norms: the perceived social pressure to perform the behavior. Perceived control: the person's estimate of his or her capacity to perform the behavior. Intentions: the readiness or willingness to perform the behavior.

The study also integrates the TPACK framework (Mishra, P., & Koehler, M. J., 2006), which emphasizes the interconnectedness of technological, pedagogical, and content knowledge. TPACK posits that effective technology integration in teaching requires a deep understanding of how these three knowledge domains interact. In this study, TPACK is explored through observation of the teachers' implementation of TSFS. Data collection includes teacher interviews to explore how their understanding of TPB, their pedagogical choices, and their technical skills in utilizing TSFS interact to facilitate effective learning. The effectiveness of the teachers' TPACK was assessed through qualitative analysis of classroom observations, which evaluated the integration of TSFS into the lesson, the teachers' ability to respond to students' needs, and the overall quality of the learning experience.

The interplay between TPB and TPACK is central to this study's design. The TPB helps to understand the factors influencing students' engagement and learning outcomes through the software. TPACK provides a framework for evaluating the teachers' implementation of the software and their ability to foster effective learning using technology. By combining these two frameworks, this study aims to gain a deeper and more holistic understanding of the factors that contribute to the successful integration of technology within game-based learning environments and their effects on both students' attitudes and their mathematical achievement. This integrated approach allows for a more complete picture of how the intervention affected student learning and engagement. Table 1 summarizes the specific measures employed for each aspect.

Table 1. Specific Measures Employed for Each Aspect

Framework	Component	Measurement Method(s)
TPB	Attitude towards GBL	Pre- and post-intervention surveys
	Subjective Norms	Pre- and post-intervention surveys
	Perceived Behavioral Control	Pre- and post-intervention surveys, interviews
	Behavioral Intention	Pre- and post-intervention surveys, observation
TPACK	Technological Knowledge	Teacher interviews, observation of software use
	Pedagogical Knowledge	Teacher interviews, classroom observations
	Content Knowledge	Teacher interviews, analysis of lesson plans
	Pedagogical Content Knowledge	Classroom observations, analysis of student work
	Technological Content Knowledge	Observation of software use, analysis of game design
	Technological Pedagogical Content Knowledge	Classroom observations, teacher interviews, student outcomes

2.4. Significance of the Study

Research on the effectiveness of game-based learning (GBL) in mathematics education is growing, yet significant gaps remain. Many studies rely on commercially available games, not those specifically designed for educational purposes, hindering conclusions about GBL's true impact. Additionally, much of the existing research uses laboratory settings or short-term interventions, limiting generalizability to real-world classrooms and understanding of long-term effects. This study addresses these limitations by: 1) developing a purpose-built educational game (TSFS) to teach challenging algebraic concepts within a geometric context, 2) implementing the game within a real-world classroom setting, and 3) conducting a long-term intervention to evaluate the sustained impact on student achievement. The findings contribute to a more nuanced understanding of GBL's potential and provide valuable insights for educators seeking to effectively integrate game-based methods into mathematics curricula.

3. Methodology

This study employed a mixed-methods, longitudinal design to investigate the impact of the TSFS software on Qatari fourth-grade students' mathematical achievement and attitudes toward mathematics. A randomized controlled trial assigned 150 students (N=150) to three groups (n=50 per group) across three classrooms within a single primary school. Prior to the intervention, all three teachers underwent a standardized two-day training program on TSFS, encompassing both software functionalities and pedagogical best practices. Teacher proficiency was assessed pre- and post-training using a validated 5-point Likert scale instrument measuring technological comfort and confidence in using educational software (Table 1). This pre-training assessment served as a control variable to account for pre-existing differences in teacher technological capabilities. To ensure intervention fidelity, a detailed implementation protocol was established and followed across all classrooms.

3.1. Participants of the Study

This study involved 144 fourth-grade students from three primary schools located in different regions across Qatar. The schools were selected based on their willingness to participate, their diverse student populations, and their established collaboration with the research team, which facilitated access and logistical support for the intervention. Including schools from different areas aimed to enhance the diversity and generalizability of the sample.

Inclusion criteria required that students be enrolled in the fourth grade at one of the selected schools, attend mathematics classes regularly, and have parental consent to participate in the study. Students with significant learning disabilities or those who were absent for more than 20% of the intervention period were excluded from the final analysis.

3.2. Data Analysis

A cluster random sampling technique was employed, with entire classrooms within each school serving as clusters. The 144 students were randomly assigned to six classrooms, with every two classrooms taught by a different teacher. Prior to the intervention, all three teachers participated in a standardized two-day training program focused on the pedagogical application and technical aspects of the TSFS software.

To ensure a baseline assessment free from prior knowledge of the study's content, all students were pre-tested before the implementation of TSFS. The intervention consisted of classroom sessions, each lasting 50 minutes, conducted over a three-month period. A mathematics coordinator from each school provided support and oversight throughout the intervention. The coordinators, alongside the six classroom teachers, also participated in post-intervention interviews.

Quantitative data were analyzed using repeated measures ANOVA to evaluate changes in students' attitudes and achievement over time, controlling for pre-existing mathematical ability (quantitative reasoning score). Structural equation modeling (SEM) was used to test the hypothesized relationships among TPB constructs and student outcomes (Figure 3). Qualitative data were analyzed using thematic analysis to identify recurring themes and patterns related to teachers' experiences, students' learning processes, and the overall impact of the TSFS intervention. Triangulation of quantitative and qualitative findings enhanced the validity and richness of the study's conclusions.

3.3. Quantitative Data Collection

Quantitative data were collected at three time points (pre-intervention, mid-intervention, and post-intervention) using the following instruments:

1. Theory of Planned Behavior (TPB) Survey: A validated 20-item instrument measured students' attitudes toward mathematics, subjective norms (perceived social pressure related to game use for learning), perceived behavioral control (self-efficacy in using TSFS), and behavioral intention toward using game-based learning. Items were scored using a 5-point Likert scale. Internal consistency reliability (Cronbach's alpha) was assessed for the survey instrument pre-intervention.

2. Mathematics Achievement Test: A standardized 30-item test, focusing on internal and external angles in triangles, was administered to assess students' knowledge and problem-solving skills. The test's reliability (Cronbach's alpha) was calculated pre-intervention.

3. Quantitative Reasoning Test: A validated 20-item test assessed students' quantitative reasoning skills, which served as a covariate to account for pre-existing mathematical ability (Floyd et al, 2006; Peters et al., 2013; Strenze, 2007).

3.4. Qualitative Data Collection

Qualitative data were collected to provide a richer understanding of the intervention's impact. Data sources included:

1. Classroom Observations: Structured observations of each classroom during TSFS implementation were conducted by two trained researchers to document student engagement and teachers' instructional practices using a pre-designed observation protocol with inter-rater reliability calculated (Cohen's kappa = 0.85). Engagement was defined by: (a) consistent focus on tasks within allocated time; (b) active manipulation of game controls; and (c) proactive seeking of assistance when encountering difficulties.

2. Semi-structured Interviews: Post-intervention semi-structured interviews were conducted with the three teachers and the school mathematics coordinator. Interview guides focused on experiences with TSFS implementation, observation of student engagement, and challenges encountered. Transcripts were analyzed using thematic analysis. In addition, student focus groups (n=6 per group) were conducted.

4. Results

The researchers assess the changes in teachers' technology comfort levels before and after the training intervention. The analysis revealed a notable increase in confidence among participants, indicating that the training was successful in enhancing their technological proficiency. Qualitative data, analyzed through thematic analysis, further complemented these findings by identifying recurring themes about teachers' experiences and the overall impact of the training. The combination of these quantitative and qualitative approaches enabled a robust understanding of both the instructional and learning processes facilitated by the training. Table 2 provides a detailed overview of the comfort levels of three teachers. Prior to the training, Teacher A reported a comfort level of 4, Teacher B scored 3, and Teacher C had a score of 2.5. Post-training, all teachers exhibited significant improvement, with Teacher A achieving a maximum score of 5, Teacher B reaching 4.5, and Teacher C increasing to a score of 4. This data underscores the positive impact of the training on teachers' comfort with technology.

Table 2. Teacher Technology Comfort Levels (Pre- and Post-Training)

Teacher	Pre-Training Comfort (1-5 Likert Scale)	Post-Training Comfort (1-5 Likert Scale)
Teacher A	4	5
Teacher B	3	4.5
Teacher C	2.5	4

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The quantitative phase of this study employed a randomized controlled trial design with 144 fourth-grade students randomly assigned to six groups. Data were collected at three time points: pre-intervention, mid-intervention, and post-intervention. A structural equation model (SEM), analyzed using AMOS 28, examined the relationships among the TPB constructs (attitude, subjective norms, perceived behavioral control) (figure 3), and student performance on a standardized algebra achievement test (controlling for pre-existing quantitative reasoning skills).

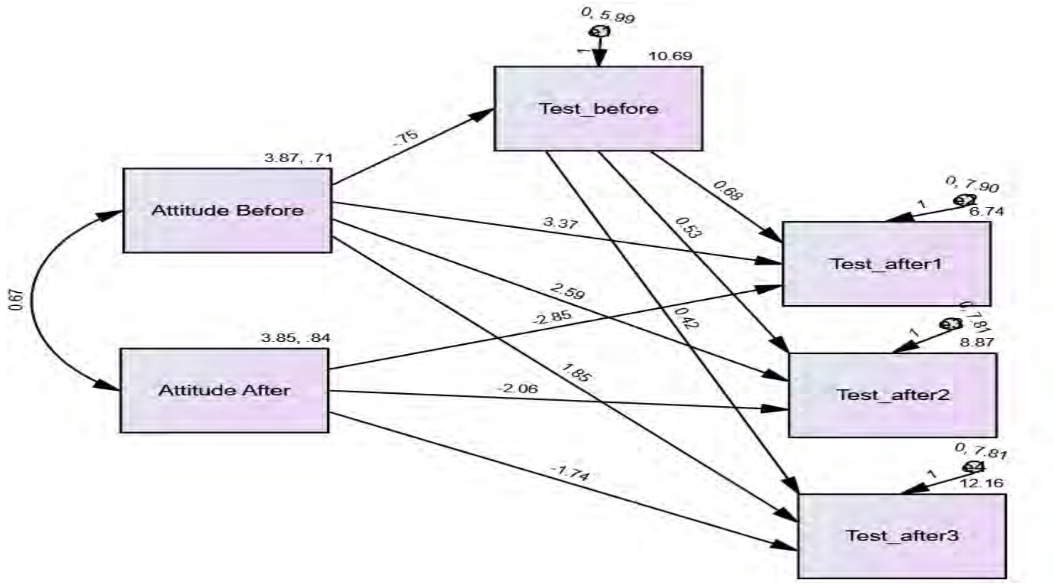

Figure 3. Structural Equation Model

The SEM model demonstrated a good fit to the data, as indicated by a non-significant chi-square ($p = .070$), a χ^2/df ratio of 1.83, and strong values for GFI (.964), NFI (.966), and CFI (.940), all exceeding recommended thresholds. The RMSEA value of .065 is also within the acceptable range (< .08). These results suggest that the model provides an adequate representation of the observed data

4.1. Analysis of TPB Constructs and Achievement

The SEM analysis revealed a significant positive relationship between students' pre-intervention attitudes toward game-based learning and their post-intervention algebra achievement scores (Table 3). This indicates that students with more positive initial attitudes demonstrated greater learning gains following the TSFS intervention. Furthermore, the longitudinal nature of the study allowed us to observe how these relationships evolved across the three measurement points. The positive effect of initial attitudes on achievement scores was maintained throughout the intervention period.

Table 3. Regression weights

Regression Weights			Estimate	S.E.	C.R.	P	Label
Test before	<---	Attitude Before	-0.747	0.555	-1.345	0.179	
Test_after1	<---	Attitude Before	3.375	1.317	2.562	0.01	***
Test_after2	<---	Attitude Before	2.591	1.31	1.978	0.048	***
Test_after3	<---	Attitude Before	1.854	1.31	1.415	0.157	
Test_after1	<---	Attitude after	-2.848	1.208	-2.358	0.018	***
Test_after2	<---	Attitude after	-2.064	1.201	-1.718	0.086	
Test_after3	<---	Attitude after	-1.736	1.202	-1.445	0.149	
Test_after1	<---	Test before	0.684	0.22	3.108	0.002	***
Test_after2	<---	Test before	0.532	0.219	2.431	0.015	***
Test_after3	<---	Test before	0.425	0.219	1.941	0.052	***

The regression results indicate that students' attitudes before the intervention were positively associated with their achievement immediately and shortly after the intervention (Test_after1: β = 3.375, $p = 0.01$; Test_after2: β = 2.591, $p = 0.048$), suggesting that initial positive attitudes supported early learning gains. However, a significant negative relationship emerged between post-intervention attitudes and achievement at the first follow-up (Test_after1: β = -2.848, $p = 0.018$), possibly reflecting a temporary focus on engagement over deep learning or cognitive overload from the novel game-based approach. This negative association diminished over time. Prior achievement (Test before) was a strong positive predictor of post-test scores across all time points, highlighting the importance of baseline ability. Overall, these findings suggest that while positive attitudes can boost early achievement, the relationship between attitudes and learning outcomes in game-based environments may be complex and evolve over time.

4.2. Changes in Attitudes and Achievement

To examine changes in students' attitudes, the Independent sample t-test was used (normality of the data) to compare pre- and post-intervention scores on the TPB survey items. This analysis revealed statistically significant positive shifts in students' attitudes towards game-based learning following the intervention (Table 4). Statistically significant improvements in algebra achievement were observed using paired samples t-tests (Table 5), indicating a positive effect of the TSFS intervention.

The Results of the attitude survey before and after the three interventions are presented in Tables 4 and 5.

Table 4. Student Attitudes Toward Learning Mathematics by Playing Games Before and After the Intervention (N = 144)

Statement	Mean Before	Mean After	% Agree	% Disagree
Is enjoyable	3.83	3.97	62.5	37.5
Is interesting	3.89	3.92	68	32
Is exciting	3.69	3.97	72.2	27.8
Is time-consuming	3.82	3.66	32	68
It is a sociable activity	3.64	3.81	75.3	24.7
It is a worthwhile activity	4.06	4.17	79.2	20.8
Helps to develop useful skills	3.81	3.92	66.7	33.3
It is a valuable activity	3.97	4.06	70.8	29.2
It is a lonely activity	3.87	3.22	29.2	70.8
It's a waste of time	3.52	2.92	21.8	78.2

Table 4 presents students' attitudes toward learning mathematics through games before and after the intervention. The results indicate a generally positive shift in perceptions following the use of game-based learning. Mean scores increased after the intervention for most positive statements, such as "is enjoyable" (from 3.83 to 3.97), "is exciting" (from 3.69 to 3.97), and "is a worthwhile activity" (from 4.06 to 4.17). The percentage of students agreeing with these positive statements was also high, with 62.5% to 79.2% agreeing that learning math by playing games is enjoyable, interesting, exciting, sociable, worthwhile, valuable, and helps develop useful skills.

In contrast, negative perceptions decreased after the intervention. For example, the mean score for "is a waste of time" dropped from 3.52 to 2.92, and for "is a lonely activity" from 3.87 to 3.22, with the majority of students (70.8% and 78.2%, respectively) disagreeing with these statements. Additionally, fewer students agreed that the approach is time-consuming after the intervention (mean decreased from 3.82 to 3.66; only 32% agreed).

Overall, these findings suggest that the game-based intervention not only increased students' enjoyment and perceived value of mathematics learning but also reduced negative attitudes, supporting the effectiveness of game-based learning in fostering more positive student perceptions of mathematics.

Table 5. Paired Samples Test Results for Achievement Scores Before and After Interventions (N = 144)

Time Point	Mean Score	p-value
Before Intervention	7.75	
After First Intervention	10.16	0.04
After the Second Intervention	12.75	0.029
After the Third Intervention	14.32	< .001

Table 5 shows a progressive increase in students' mathematics achievement scores across the three intervention periods. The mean score rose from 7.75 before the intervention to 10.16 after the first intervention ($p = .040$), 12.75 after the second intervention ($p = .029$), and 14.32 after the third intervention ($p < .001$). Each increase was statistically significant, indicating that repeated exposure to the game-based learning intervention was associated with continuous and meaningful improvements in student achievement. These results provide strong evidence for the effectiveness of the TSFS software in enhancing mathematics learning outcomes among Qatari middle school students.

The findings presented in Tables 3, 4, and 5 strongly support the study's hypotheses. The positive relationship between initial attitudes towards game-based learning and subsequent algebra achievement demonstrates the importance of fostering positive attitudes towards this innovative approach. The statistically significant improvements in both attitudes and achievement scores following the TSFS intervention further confirm the effectiveness of TSFS as a tool for enhancing mathematics learning.

4.3. Qualitative analysis

Qualitative data, gathered through classroom observations and semi-structured interviews, provided insights into the students' and teachers' experiences with the TSFS intervention. Classroom observations revealed high levels of student engagement during the intervention sessions. Students were largely self-directed, actively participating in the game and seeking assistance only when necessary. Minimal teacher intervention was required, with the teachers primarily acting as facilitators and providing support upon request. The collaborative nature of the learning environment was noteworthy, with students frequently helping and encouraging each other, even when working individually on their tasks. These observations support the quantitative findings indicating increased student motivation and positive attitudes towards game-based learning.

4.4. Thematic Coding Process

Qualitative data were analyzed using a thematic analysis approach (Braun & Clarke, 2006). All interview transcripts and observation notes were first read in full to gain familiarity. Next, initial codes were generated by identifying recurring ideas and patterns in the data. These codes were then grouped into broader themes that captured key aspects of students' and teachers' experiences with the TSFS intervention. To enhance credibility, two researchers independently coded a subset of transcripts and discussed discrepancies until consensus was reached. The final themes were refined and supported with representative quotes

4.5. Student Perspectives

1. Increased Engagement and Enjoyment

Most students reported that the TSFS software made learning mathematics more enjoyable and engaging. Classroom observations revealed high levels of student engagement, with students actively participating in the game, working independently, and seeking assistance only when necessary. As one student shared, "It is so fun to learn math in this way, at least it is not boring anymore, and finally we can understand it" (Lara). Many students described the lessons as "exciting" and "motivating," and teachers noted that even typically quiet students became more involved.

2. Improved Understanding and Visualization

A significant number of students felt that TSFS helped them visualize mathematical concepts more effectively than traditional methods. For example, Sara commented, "It helped me because I can see the path of my answers, whether I am moving in the right direction or not." Several students mentioned gaining a deeper understanding of algebraic concepts as a result of the interactive and visual nature of the software.

3. Autonomy and Collaboration

Students appreciated the opportunity to work independently while also collaborating with peers. Observations indicated that students frequently helped and encouraged each other, even when working individually. Soha noted, "Learning mathematics using games helped me feel free in solving mathematics problems and not be tied up."

4. Challenges and Suggestions for Improvement

While feedback was largely positive, a minority of students expressed concerns about the game's pace and difficulty, suggesting a need for adjustable levels. One student remarked, "Sometimes the game is too fast for me, and I wish I could slow it down." Additionally, some students initially struggled with the software interface or experienced internet connectivity issues. Specifically, 21% of students (n = 30) had difficulty navigating the software at first, 11% (n = 17) encountered connectivity problems, and 7% (n = 10) were unfamiliar with certain functionalities. These issues diminished as students gained experience with TSFS.

4.6. Teacher and Coordinator Perspectives

1. Student Engagement and Learning

Teachers observed increased motivation and participation among students during TSFS sessions. They noted that students were more eager to engage with mathematics and often persisted longer on challenging tasks.

2. Classroom Management and Practical Challenges

Teachers reported some difficulties in managing classroom dynamics during game sessions, particularly when students progressed at different rates or encountered technical problems. One teacher commented, "It can be hard to keep everyone on task when some students finish early or encounter technical problems."

3. Role of GBL in Curriculum

Both teachers and the mathematics coordinator expressed that while TSFS was effective for boosting engagement and understanding, it should complement rather than replace traditional

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instruction. The mathematics coordinator stated, "GBL works best alongside other teaching methods, not as a stand-alone solution."

4. Implementation Barriers

Concerns were raised about the technical requirements and costs associated with implementing GBL. Teachers emphasized the need for cost-effective, accessible software and additional training to maximize the benefits of such interventions.

The qualitative findings provide a nuanced and balanced understanding of the TSFS intervention's impact. While most students and teachers reported positive experiences and improved attitudes toward mathematics, some challenges and reservations were also identified. The thematic analysis process and the inclusion of both positive and critical perspectives enhance the credibility of the findings. Overall, the qualitative data strongly reinforce the quantitative results, illustrating how TSFS improved student engagement, understanding, and attitudes, while also highlighting practical considerations for successful implementation of game-based learning in mathematics classrooms.

5. Discussion

This study's findings provide compelling evidence supporting the integration of game-based learning (GBL) in mathematics education, aligning with the growing body of research emphasizing the importance of active learning and student-centered pedagogies (Hamari et al., 2014; Nacke & Deterding, 2017). The results demonstrate that a well-designed and implemented GBL intervention, such as the TSFS software, can significantly impact both student attitudes and achievement, confirming the potential of GBL to address the persistent challenges in mathematics education (as discussed in the literature review, Buckley & Doyle, 2014; Bicen & Kocakoyun, 2018).

The significant positive shifts observed in students' attitudes toward mathematics (Table 3), as measured by the TPB constructs, directly support previous research highlighting the motivational power of games in fostering engagement and enhancing learning experiences (Garris, Ahlers, & Driskell, 2002; Denham, 2019). The increased enjoyment, perceived usefulness, and reduced feelings of anxiety reported by students align with GBL's ability to transform learning into a more positive and less intimidating experience (Devlin, 2011). The qualitative data further enriches this finding by illustrating how the interactive and collaborative nature of TSFS fostered a supportive learning environment where students felt empowered and encouraged to actively participate in the learning process. Students' comments regarding the game's ability to help them visualize concepts and understand solution pathways align with the literature emphasizing the effectiveness of visual representations in improving mathematical understanding (McGuffey, 2015; Tokac, Novak, & Thomson, 2018).

Furthermore, the study's findings demonstrate a strong positive correlation between students' pre-intervention attitudes toward game-based learning and their subsequent achievement scores (Table 2), underscoring the importance of addressing affective factors in mathematics education (as noted in the literature review - Buckley & Doyle, 2014; Bicen & Kocakoyun, 2018). This highlights the need for educators to foster positive attitudes and beliefs about mathematics to maximize the effectiveness of any instructional intervention, including GBL. The significant improvement in algebra achievement scores following the TSFS intervention (Table 4) directly supports previous research indicating that GBL can lead to positive learning outcomes (Chaaban et al, 2024; Bai et al., 2010; Clark et al., 2016). However, the qualitative data reveal that merely introducing GBL is not sufficient; effective implementation depends heavily on teacher expertise and preparedness.

The teachers' perspectives, as revealed in the post-intervention interviews, provide valuable insights into the practical challenges associated with integrating GBL into classroom settings. Their concerns about classroom management and the need for ongoing professional development

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highlight the importance of providing adequate teacher training and support. This is crucial for successful GBL implementation and aligns with the emphasis on TPACK (Mishra & Koehler, 2006), which highlights the interconnectedness of technology, pedagogy, and content knowledge. While acknowledging the software's potential, some teachers expressed reservations about its suitability as the primary method of instruction, suggesting that GBL should serve as a supplementary, yet essential tool within a broader teaching approach. This aligns with ongoing discussions in the literature regarding the optimal integration of GBL within a balanced instructional framework (Gee, 2024; Kapp,2012; Nicolaidou et al., 2022). The study's findings emphasize the critical role of teacher TPACK in fostering successful technology integration in education, echoing the need for effective teacher training to maximize the benefits of GBL and minimize the associated challenges.

6. Conclusion

This study investigated the impact of a game-based learning (GBL) intervention, utilizing the Test Survey for Students (TSFS) software, on the mathematical achievement and attitudes of Qatari fourth-grade students. Employing a rigorous mixed-methods design, incorporating the Theory of Planned Behavior (TPB) and Technological Pedagogical Content Knowledge (TPACK) frameworks, this research yielded robust evidence supporting the efficacy of well-designed and effectively implemented GBL in enhancing mathematics learning.

The findings demonstrate a significant positive relationship between students' pre-intervention attitudes toward game-based learning and their subsequent algebra achievement, underscoring the importance of fostering positive learning environments. Furthermore, the TSFS intervention resulted in statistically significant improvements in both students' attitudes towards mathematics and their achievement scores. These quantitative findings are strongly supported by qualitative data, which revealed high levels of student engagement, positive feedback on the software's design and usability, and the collaborative nature of the learning experience.

However, the qualitative data also highlighted the importance of addressing both pedagogical and practical challenges associated with implementing GBL in real-world classroom settings. Teachers expressed concerns regarding classroom management during game-based activities, emphasizing the need for ongoing professional development and sufficient training in using educational software. While the findings strongly support the effectiveness of TSFS in enhancing mathematics learning, the study also revealed that merely introducing GBL is not sufficient. The success of GBL hinges on careful planning, integration within a broader instructional framework, and adequate teacher preparation and support to address both technological and pedagogical challenges. Further research is needed to explore the long-term effects of TSFS and to develop strategies for supporting teachers in effectively integrating GBL into their teaching practices.

This study contributes significantly to the field of game-based learning in mathematics by providing strong empirical evidence of its effectiveness and by highlighting the crucial role of both student attitudes and teacher expertise in optimizing learning outcomes. The findings offer valuable insights for educators and researchers alike, informing the design and implementation of effective game-based learning interventions that can enhance students' engagement, motivation, and ultimately, their mathematical achievement. Future research should focus on addressing the identified limitations, including the need for more robust assessment tools specific to game-based learning, investigation of the long-term impact of this type of intervention, and the development of comprehensive teacher training programs to address the pedagogical and technological challenges inherent in implementing GBL successfully.

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7. Suggestion

Based on the findings of our study, future research should explore the long-term effects of the TSFS intervention on student achievement and attitudes, tracking participants beyond the initial three-month period. Investigating the impact of varying levels of teacher TPACK on student outcomes would provide valuable insights into effective GBL implementation strategies. Additionally, studies could examine the transferability of the TSFS model to other mathematical concepts and grade levels. It would also be beneficial to explore the integration of culturally relevant content and game mechanics to further enhance the relevance and engagement of GBL interventions in the Qatari context. Finally, assessing the cost-effectiveness of TSFS compared to traditional teaching methods would inform decisions regarding resource allocation and educational investments.

Declarations

Author Contributions. (Dr.Areej.: Literature review, conceptualization. Dr. Hiba: methodology, data analysis. Dr. Mayamin: review-editing and writing, original manuscript preparation. All authors have read and approved the final version of the article.

Conflicts of Interest. The authors declare no conflict of interest.

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Ethical Approval. The research was approved by the International Research Board (IRB) at Qatar University, under approval number QU-IRB 1735-EA/22. Informed consent was obtained from all human participants prior to their involvement in the study, ensuring they were fully aware of the research purpose and procedures. For any inquiries regarding the ethical compliance of this study, please contact QU-IRB at QU-IRB@qu.edu.qa or by phone at 4403 5307.

Data Availability Statement. Available upon request in the repository

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