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Empowering grade 8 learners through game-based learning: Enhancing achievement in square and cube roots

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A B S T R A C T

Understanding square and cube roots is essential for grade 8 students, as these concepts form the foundation for more advanced topics in algebra and other areas of mathematics. However, many students find these topics difficult, which can affect their overall progress in mathematics. To address this issue, this study explored the use of Game-Based Learning (GBL) to improve students' academic performance and engagement. The study aimed to examine the impact of GBL on the learning achievement of Thai grade 8 students in square and cube roots and to evaluate their satisfaction with the learning experience. A one-group experimental design was used with 43 grade 8 students from a public school in Thailand. The main tools included a GBL learning management plan, an achievement test, and a learning satisfaction questionnaire. Data were analyzed using percentage, mean, standard deviation, and a dependent sample t-test. The results showed a significant improvement in students' learning achievement and a high level of satisfaction with the GBL approach. These findings suggest that GBL can be an effective method for improving learning outcomes and student motivation in mathematics education.

1. Introduction

Learning square and cube roots can be difficult for many grade 8 students. These topics are important because they help students understand more advanced areas of mathematics later on. However, traditional teaching methods often do not make these ideas clear or interesting. One way to improve this is through game-based learning (GBL), which uses games to make learning more fun and engaging. This study looks at how GBL can help Thai Grade 8 students do better in math, especially when learning about square and cube roots, and how satisfied they feel with this way of learning.

The results are consistent with the findings of Brezovszky et al. (2019), Tokac et al. (2019), White and McCoy (2019), Vankúš (2021), Irwanto et al. (2024), Hidayat et al. (2024), and Chang et al. (2024), who demonstrated the efficacy of GBL, particularly in mathematics education for young learners. GBL's success lies in its ability to create engaging and interactive learning experiences through game-based activities, which motivate students and promote active participation in the learning process.

GBL is particularly effective in teaching square roots and cube roots because it transforms abstract mathematical concepts into concrete, hands-on experiences. Through games, students can visualize and manipulate these concepts in a fun and stimulating environment, making complex ideas more accessible and easier to understand. For example, games that involve solving puzzles or completing challenges based on square roots and cube roots can help students practice and reinforce their skills in a low-stress setting.

The results can be attributed to the engaging and interactive nature of GBL activities, which fostered a sense of enjoyment and enthusiasm among participants. GBL is a teaching method that utilizes games to enhance the learning process, promote cognitive skill development, increase motivation, and help learners embrace failure, making it a valuable alternative to traditional teaching methods in educational settings. GBL also serves as an interactive instructional tool that actively fosters student engagement. It can be customized for various subjects, including Tajweed, and

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incorporates motivational design elements to enhance students' motivation and learning success (Ramlan et al., 2025). According to Coleman (2011), students in middle school require exciting and engaging learning environments to effectively learn, and the GBL effectively fulfills this need, resulting in a positive and rewarding learning experience for the participants.

In mathematics education, the comprehension of square and cube roots stands as a pivotal milestone in a student's journey. Square roots, denoted by the radical symbol (√), represent the inverse operation of squaring a number, revealing the value that, when multiplied by itself, equals a given number. Similarly, cube roots extend this concept to finding the number that, when multiplied by itself twice, equals a given value. These fundamental operations serve as the cornerstone for understanding higher-level mathematical concepts and play a crucial role in shaping students' mathematical proficiency throughout their academic endeavors. Beyond their immediate application, mastery of square and cube roots facilitates a deeper comprehension of various mathematical principles, including algebraic expressions, equations, and geometric properties. Furthermore, the practical utility of these operations transcends the confines of the classroom, offering invaluable tools for problem-solving in real-world scenarios such as engineering, finance, and scientific research. Thus, the acquisition of skills related to square and cube roots not only enhances students' mathematical abilities but also equips them with essential tools for navigating complex problems across diverse fields of study and practical applications.

However, the mastery of square and cube roots is not easily attained, as it necessitates a firm grasp of various foundational mathematical concepts. To effectively understand and manipulate square and cube roots, students must first possess a solid understanding of basic arithmetic operations, including addition, subtraction, multiplication, and division. Additionally, proficiency in exponentiation and the concept of powers is essential, as square roots can be thought of as the inverse operation of raising a number to the power of two, while cube roots correspond to the inverse operation of raising a number to the power of three. Furthermore, familiarity with numerical properties, such as factors, multiples, and prime numbers, is indispensable for recognizing patterns and simplifying root expressions. Without these prerequisite skills and conceptual frameworks in place, the comprehension of square and cube roots can prove challenging for students, hindering their ability to fully engage with and apply these concepts in mathematical problem-solving. It is not surprising, then, that many students struggle to grasp the intricacies of square and cube roots, contributing to the perception of mathematics as one of the most daunting subjects in school (Karagiannakis et al., 2014). The cumulative nature of mathematical learning, coupled with the inherent complexity of root operations, underscores the importance of providing comprehensive support and targeted instruction to facilitate students' understanding of these fundamental mathematical concepts.

Thailand, as the contextual area of this study, faces significant challenges in the realm of mathematics education, including in navigating complex concepts such as powers and roots (OECD, 2022). Thai students encounter difficulties in mastering these concepts, reflecting broader issues within the educational landscape. Criticisms abound regarding various aspects of the educational context, notably the shortage of qualified mathematics teachers. This dearth often results in teachers being tasked with instructing multiple subjects within their classes, a common occurrence in public elementary schools, particularly those situated in rural areas. This prevalence can be attributed to the centralized structure of the country's government. Furthermore, instructional practices that fail to cater to students' needs exacerbate the situation. Lecture-based, teacher-centered approaches, coupled with exercises lacking clear instructions, fail to engage students or align with their learning preferences. Such shortcomings are reflected in both domestic and international test results (OECD, 2022). Moreover, Thailand's status as a technology-receptive nation underscores the broader ramifications of deficiencies in science, technology, engineering, and mathematics (STEM) education, which forms the foundation of national technological development.

At the age of Grade 8, students need a stimulating and interactive environment that connects with their experiences and interests in order to facilitate learning. During this phase, which is usually characterized by the beginning of adolescence, students have a strong desire for learning experiences that are both pertinent and stimulating, as well as interactive (Meier and Sisk-Hilton, 2013). Teen students exhibit an innate inquisitiveness and vitality, but they are also prone to quickly disinterested, especially when faced with conventional, lecture-oriented teaching methods (Coleman, 2011). Passive learning methods are ineffective in engaging their attention or encouraging their active involvement in the learning process. On the contrary, students excel in settings that provide practical experiences, cooperative assignments, and chances for investigation and revelation (Papazoi et al., 2017). Grade 8 students are more likely to be enthusiastic about learning and achieve better educational outcomes when they have meaningful and relatable learning experiences that are presented in engaging formats. This is supported by research conducted by Coleman (2011) and Meier and Sisk-Hilton (2013).

In this case, GBL leverages the motivational and engagement benefits of games to enhance learning outcomes. GBL integrates game elements, such as competition, rewards, and interactivity, into educational activities to make learning more enjoyable and meaningful. By incorporating game mechanics, such as challenges, levels, and feedback, GBL captivates students' attention, promotes active learning, and reinforces key concepts in an immersive and interactive manner. It may be possible for learners to comprehend complex mathematical concepts using games designed specifically for math education.

Previous studies have increasingly focused on the utilization of GBL in the realm of mathematics education, with notable attention paid to its effectiveness in fostering knowledge development (Brezovszky et al., 2019; Khoirunnisya et al., 2024; Tokac et al., 2019; White and McCoy, 2019; Vankúš, 2021; Sun et al., 2021). The outcomes of these studies consistently demonstrate positive results associated with GBL methodologies. Previous research has urged the use of GBL in a broader range of mathematical concepts, emphasizing its potential for more complex areas of math. Karali (2022) noted that mathematics becomes challenging for students when it requires the application of multiple concepts simultaneously. Testing GBL in the instruction of square roots and cube roots might contribute significantly to the field, demonstrating that GBL can be effective in teaching complex mathematical concepts, rather than merely serving as fun activities that support learning.

Therefore, the current study has adopted the principles of the GBL to construct a comprehensive learning management plan aimed at enhancing the learning achievement of Thai grade 8 students in the realm of square and cube roots. This research endeavor holds significant promise in contributing to the field, as it seeks to provide empirical evidence supporting GBL as a potent tool for developing mathematical concepts among teen learners. Moreover, the research aims to demonstrate the potential of GBL to create a synergistic learning environment that optimizes the educational experience within mathematics classrooms. The insights gained from this study have the potential to inform pedagogical practices and curriculum design, ultimately enriching mathematics education for grade 8 students in Thailand and beyond. The aims of this research were as follows: 1) assess the impact of game-based learning management on the academic performance of eighth-grade students in acquiring knowledge of square roots and cube roots; and 2) investigate the level of satisfaction among the participants regarding the utilization of game-based learning activities to learn these concepts.

2. Literature review

Scholars have provided insights into defining and measuring learning achievement. Bolt (2011) posited that learning is a process of exerting effort to acquire new behavioral changes as a result of personal experiences interacting with the environment. Similarly, Pandey and Thapa (2017) emphasized that learning outcomes aim to gauge the extent of students' behavioral changes following the learning process, typically assessed through tests. These assessments yield numerical or qualitative data reflecting students' mastery of the subject matter, commonly referred to as learning achievement. de la Iglesia and Solano (2019) further elucidated that learning achievement can be assessed through various means, primarily through tests designed to measure students' abilities and the effectiveness of teaching programs based on test scores.

In the context of mastering square and cube roots, students require a combination of knowledge and skills to achieve learning outcomes. Firstly, they need a solid understanding of basic arithmetic operations such as addition, subtraction, multiplication, and division. Proficiency in exponentiation and the concept of powers is essential, as square roots represent the inverse operation of squaring a number, while cube roots correspond to the inverse operation of raising a number to the power of three. Additionally, familiarity with numerical properties such as factors, multiples, and prime numbers aids in recognizing patterns and simplifying root expressions. Mastery of these foundational concepts lays the groundwork for comprehending and manipulating square and cube roots effectively.

Therefore, learning achievement in mathematics roots encompasses the acquisition of knowledge and skills necessary to understand, manipulate, and apply square and cube roots effectively. It involves a process of acquiring new behavioral changes through interactive experiences and is typically assessed through tests or other measuring instruments. Achieving learning outcomes in mathematics requires students to demonstrate proficiency in arithmetic operations, exponentiation, and numerical properties, enabling them to navigate complex mathematical concepts with confidence and accuracy.

GBL offers a dynamic approach to education, aiming to strike a balance between theoretical content and experiential learning through the use of games (Dichev and Dicheva, 2017). Chen et al. (2018) emphasized that game-based learning provides students with opportunities to engage with challenging learning environments and targeted educational outcomes. To ensure effectiveness, educational games should be designed to maintain student interest and engagement over repeated cycles within the game context, thereby preventing boredom while eliciting desirable behaviors and cognitive reactions (Boctor, 2013). Post-game debriefings serve as a crucial component of game-based learning, facilitating the connection between the game world and real-life scenarios. This process allows students to reflect on their experiences, understand key learning outcomes, and apply acquired knowledge in practical situations (Triantafyllou and Farhaoui, 2024). Games in the GBL approach, characterized by their purposeful blend of education and entertainment, offer a particularly engaging approach to game-based learning (Bundick et al., 2014). By presenting deterministic problems and offering players the autonomy to navigate through challenges and solve puzzles, adventure games foster problem-solving skills and enhance players' ability to identify solutions in a variety of contexts (Boctor, 2013).

As previously stated, GBL effectively promotes the development of mathematical knowledge, according to a large body of research (Brezovszky et al., 2019; Khoirunnisya et al., 2024; Tokac et al., 2019; White and McCoy, 2019; Vankúš, 2021; Sun et al., 2021). As noted by Karali (2022), the application of numerous concepts to mathematics is challenging. GBL could be evaluated in challenging mathematical instruction that goes beyond engaging learning activities, such as when cube roots and square roots are taught. The present study employs GBL principles to develop an all-encompassing learning management system with the aim of enhancing the square and cube root abilities of eighth-grade Thai students. This research may demonstrate the efficacy of GBL in instructing teen learners in grade 8 in the mathematical concepts of cube root and square root. In an effort to optimize mathematical learning, it establishes a synergistic learning environment.

3. Methods

The study followed a One-Group Pretest-Posttest Design. Participants' performance was assessed at three main stages: before starting the activities in the GBL management plan, during its implementation, and after completing the intervention. In addition, participants' satisfaction with the intervention was measured to provide further insight into the study's results (Table 1).

Table 1: One-group pretest-posttest design

Phase	Activity/intervention	Data collection instruments
Before	Pretest	Achievement test
Between	GBL plan	The GBL learning management plan
After	Posttest	Achievement test Learning satisfaction questionnaire

The study involved 43 Grade 8 students from Room 1 (Form 11 Room) of a public school in the Thai education system. The participants were selected using a cluster sampling method. Ethical guidelines for human research were strictly followed throughout the study.

The Game-Based Learning (GBL) management plan on the topic "Square Roots and Cube Roots" required a total of six hours to complete. The content included: 1) Square roots, 2) Use of the square root symbol, 3) Relationships of squares, 4) Estimating square roots, 5) Cube roots, and 6) Relationships of cubes. The appropriateness of the lesson plans was evaluated by three experts and rated at a very high level (Mean = 4.78). The design of the lesson plan is presented in Table 2. Examples of gameplay:

1. The instructor partitions the students into groups. Communicate the regulations of the game
2. Subsequently, rotate the wheel to randomly designate a group of pupils to unveil the plaque.
3. Random group, accessing the nameplate on the website wordwall.net/resource/37605618.
4. Students within the group assist one another in calculating the solution; if the answer is accurate, if the answer is true, they will access the scoreboard, which will reflect +10, +15, +20, etc.

In this game, students are required to engage with the material in a way that challenges their problem-solving abilities. The cognitive load is designed to encourage them to make connections between concepts, such as square roots, the use of square root symbols, the relationship between squaring and square roots, approximating square roots, cube roots, and the relationship of cubing. For example, a question may ask, "Is the square root of 512 greater than the square root of 49?" requiring students to evaluate numbers, understand their relationships, and choose the correct option based on their understanding of the concept.

Table 2: Contents and games on the topic of "square roots and cube roots"

Lesson plans	Application use play games
Square roots	Kahoot
Using the symbol of the square root	BINGO
The relationship of squares	Quizizz
Square root estimation	Wordwall and Crowd Buzzer
Cube roots	Wordwall
Relationships of cubes	Wordwall

The test consists of 20 multiple-choice items, amounting to a total of 20 points. This test format is employed both as a pretest and a posttest. The Index of Congruence (IOC) of the item was at 1.00. Multiple-choice discrimination ranges from 0.24 to 0.81 using B-index and reliability tested at 0.99 using Lovett's method.

The questionnaire was designed to evaluate participants' satisfaction with the GBL learning management plan. It consisted of 10 positive statements pertaining to their learning experiences with the plan. Administered after the treatment concluded, the questionnaire offered valuable insights into participants' perceptions of the learning management plan. The Index of Congruence (IOC) of the item was recorded at 1.0.

3.1. Data analysis

Data analysis involved the use of percentage, mean, and standard deviation to evaluate pretest scores, posttest scores, and participants' satisfaction with the learning management plan. The Shapiro-

Wilk test was used to assess the normality of the data, and a Dependent Samples t-test was conducted to compare the pretest and posttest scores (Montgomery and Runger, 2010).

4. Results

The study results are analyzed with a focus on two main aspects: 1) The comparison of participants' learning achievement before and after the treatment, and 2) The satisfaction of participants with the learning management. The specific details of each analytical aspect are outlined below.

4.1. The comparison of participants' learning achievement before and after the treatment

A. Test normality: Before conducting the mean comparison analysis, both the pretest and posttest data underwent Shapiro-Wilk tests, confirming their normal distribution. The results show that all the data sets gathered in the current study were in a normal distribution. Both Shapiro-Wilk tests indicate no significant abnormality in data distribution ($p>0.05$) in Table 2. Consequently, a paired sample t-test, a parametric statistic, was utilized (Table 3).

Table 3: Normality of data

Timepoint	Shapiro-Wilk		
	Chi-square (χ^2)	df	P-value
Posttest	0.950	43	0.060
Pretest	0.949	43	0.055

P > .05 means no significant abnormality in data distribution

B. The results revealed a significant enhancement in participants' learning achievement regarding square and cube roots following the implementation of the learning management plan. Specifically, the dependent sample t-test unveiled a notable disparity between the participants' average pretest score ($\bar{x}=5.16$) and posttest score ($\bar{x}=15.28$), with $t=32.01$, $p=0.00$. These findings underscore the positive impact of the game-based learning management plan on participants' knowledge of square and cube roots. (Table 4).

Table 4: Dependent sample t-test

Learning achievement	Full mark	$\bar{x}$	SD	t-test	P-value
Posttest	20	15.28	2.29	32.01	.00
Pretest	20	5.16	2.22		

SD: Standard deviation

4.2. The satisfaction of participants with the learning management

The findings reveal that participants expressed a high level of satisfaction with their learning experiences using the GBL. This satisfaction is reflected in their agreement with the positive items concerning the learning management plan. Notably, collaborative experiences facilitated, enjoyable learning experiences offered by the GBL, and engaging in practical activities all contributed to making the classroom environment more enjoyable for the participants. These aspects of the learning approach fostered a positive and engaging atmosphere, enhancing the overall learning experience for the participants (Table 5).

Table 5: Participants' satisfaction with the learning management plan

No.	Items	$\bar{x}$	SD	DF
1	Learning activities fostered the exchange of ideas.	4.16	0.92	High
2	Learning activities ignited my enthusiasm for learning.	4.14	0.68	High
3	I felt more unity when engaging in activities with the group.	4.02	0.71	High
4	Playing games while learning made it easy for me to understand the content.	4.35	0.75	High
5	Playing games while learning made the class more active.	4.07	0.77	High
6	Playing games while learning made me feel more comfortable learning mathematics.	4.30	0.71	High
7	Playing games while learning made my classmates more eager to share ideas with me.	4.21	0.80	High
8	Practical activities helped me improve my quick-thinking skills.	4.16	0.81	High
9	Practical activities made me enjoy mathematics.	4.14	0.89	High
10	Practical activities made me feel like I own my learning.	4.17	0.71	High
	Average	4.17	0.76	High

DF: Degree of agreement

5. Discussion

The results of the study reveal that the learning management plan achieved a desirable level compared to predefined criteria, resulting in noticeable improvements in participants' learning achievement, as indicated by the comparison of pre- and post-test scores. Thus, it can be inferred that the integration of GBL was effective in enhancing participants' understanding of square and cube roots. This finding aligns with previous research conducted by Brezovszky et al. (2019), Tokac et al. (2019), Vankúš (2021), and White and McCoy (2019), who demonstrated the efficacy of GBL, particularly in mathematics education for young learners. GBL's success lies in its ability to create engaging and interactive learning experiences through game-based activities, which motivate students and promote active participation in the learning process. Additionally, studies have shown that GBL tools, such as Quizizz and Kahoot, significantly enhance students' mathematical problem-solving skills and overall learning performance. For instance, Bicen and Kocakoyun (2018) found that using Quizizz as a game-based learning tool significantly improved students' academic performance and motivation, highlighting its potential for enhancing learning outcomes through interactive quizzes. Similarly, Licorish et al. (2018) reported that using Kahoot in classroom settings improved students' engagement and performance, showing how game-based platforms can enhance understanding and support analytical skill development. Moreover, Orbon and Sapin (2022) found that game-based learning materials effectively enhanced students' mathematical problem-solving abilities and overall academic performance. These findings further reinforce the effectiveness of GBL in improving students' learning outcomes, particularly in mathematics education.

Additionally, GBL serves as an educational approach that utilizes games to enhance student motivation and learning outcomes. This study supports the effectiveness of GBL, particularly with applications such as Educandy, in significantly improving student engagement and academic performance compared to traditional teaching methods (Lioni and Friyatmi, 2024). GBL is also recognized as an instructional method that incorporates game elements to teach knowledge and values, such as Islamic principles, enhancing student engagement while making the learning process more interactive and enjoyable. Furthermore, Kahoot! has been employed as a GBL tool to promote active learning in statistics, significantly increasing students' learning activities from 42.4% to 71.3% (Pardede and Listiani, 2024). These findings collectively reinforce the effectiveness of GBL in fostering interactive, engaging, and student-centered learning environments, ultimately leading to improved learning outcomes. The results of the study also indicate that participants experienced a satisfying learning atmosphere within the learning management plan. This can be attributed to the engaging and interactive nature of GBL activities, which fostered a sense of enjoyment and enthusiasm among participants. According to Coleman (2011), teen students require exciting and engaging learning environments to effectively learn, and the combination of GBL effectively fulfills this need, resulting in a positive and rewarding learning experience for the participants.

6. Conclusion

The study utilized the GBL method to devise a comprehensive learning management plan aimed at enhancing the learning achievement of grade 8 students in Thailand, particularly in the domains of square and cube roots. Two primary findings emerged from the study: Firstly, the GBL method resulted in notable improvements in participants' learning achievement; secondly, it fostered satisfying learning experiences within the mathematics classroom. The findings of this study carry significant implications for teaching and suggest avenues for further research. Firstly, educators can adopt the GBL approach to enhance student learning outcomes in mathematics, particularly in understanding complex concepts like square and cube roots. By incorporating interactive games that require students to solve real-world problems using these concepts, GBL can help make abstract mathematical ideas more tangible and relatable. For example, games that involve comparing and approximating square and cube roots or solving equations that incorporate these concepts can provide students with immediate feedback, allowing them to refine their understanding in real time.

Furthermore, the study underscores the value of GBL in fostering student engagement and active participation in mathematics classes, particularly with young learners. Unlike traditional methods where students passively receive information, GBL encourages learners to actively interact with mathematical content, challenge their problem-solving abilities, and develop a deeper understanding of concepts through exploration and practice. The use of GBL can turn learning into an enjoyable and motivating experience, helping students stay engaged while simultaneously strengthening their mathematical reasoning and skills. It must be acknowledged that the use of a one-group experimental design is a significant limitation of this study. Without a control group for comparison, the findings may be influenced by external variables or biases that were not accounted for. While the study provides valuable insights into the effectiveness of the GBL method, the lack of a comparative group limits the ability to generalize the results more broadly. Additionally, the study was conducted with a relatively small sample size, which may restrict the generalizability of the findings to larger and more diverse student populations. A small sample size increases the likelihood of variability in results and may not fully capture the broader impact of GBL on different student demographics.

Future research employing a more robust experimental design, such as a randomized controlled trial, could offer a clearer understanding of the GBL method's impact on student learning achievement and its potential applicability across diverse educational contexts. Expanding the sample size to include a larger and more representative group of students would further strengthen the reliability of the findings and provide a more comprehensive evaluation of the effectiveness of GBL. Additionally, conducting longitudinal studies that track student progress over time could offer deeper insights into the long-term benefits of GBL in fostering academic success and engagement.

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Compliance with ethical standards

Ethical considerations

This study was conducted in compliance with ethical standards. All participants provided informed consent prior to participation, and their privacy and confidentiality were protected throughout the study.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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