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Improving Grade 9 students' mathematics achievement in similarity through game-based learning

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ABSTRACT

The purpose of this study was to develop game-based learning lesson plans on the concept of similarity for Grade 9 mathematics, evaluate students' learning achievement before and after instruction, and examine their satisfaction with this approach. The study employed a quasi-experimental one-group pretest–posttest design. The participants consisted of 11 Grade 9 students from Triam Udomsuksa Pattanakan Roi Et School. The research instruments included nine game-based lesson plans, an achievement test, and a satisfaction questionnaire. Data were analyzed using the Wilcoxon Signed Ranks Test, along with percentage, mean, and standard deviation. The results indicated that students' posttest scores were significantly higher than their pretest scores at the 0.05 significance level. In addition, the students' overall satisfaction with the game-based learning approach was at the highest level. This study contributes empirical evidence supporting the effectiveness of game-based learning as a pedagogical approach for improving both academic achievement and student engagement in secondary mathematics.

1. Introduction

Similarity is a cornerstone topic in secondary mathematics. It connects proportional reasoning, ratio and scale, and transformational geometry, and it underpins later ideas such as trigonometry, indirect measurement, and geometric modeling (Greenwald and Thomley, 2024). Mastery of Similarity supports students' ability to interpret diagrams, reason with scale factors, and transfer geometric structure across contexts (Grigoriadou et al., 2021)—capabilities that align with Thailand's curriculum emphasis on analytical thinking and real-world problem solving in the 21st century.

Despite its centrality, Similarity is conceptually demanding. Students must coordinate angle equality with proportional side lengths, distinguish similarity from congruence, and reason with ratios rather than differences (Herbst et al., 2017). These demands often produce persistent misconceptions (e.g., applying an additive change instead of a multiplicative scale factor) and lead to low confidence and disengagement in mathematics learning (Jones, 2002; Juman et al., 2022).

At the contextual level, achievement data signal a need for improvement. While Grade 9 students at Triam Udomsuksa Pattanakan Roi Et School exceeded provincial and national benchmarks in 2021, mean O-NET mathematics scores fell below provincial, OBEC, and national averages in 2022 and 2023, indicating sustained challenges that require a more engaging and effective instructional response.

One contributing factor is the persistence of traditional lesson formats dominated by explanation, demonstration, and teacher talk. Such routines often fail to capture attention or promote active sense-making, which can contribute to boredom and underperformance (Ting et al., 2023)—especially in abstract topics like Similarity. Calls for diversified, technology-supported pedagogy in Thailand highlight the need to increase learner participation and address varied readiness levels (Tiengyoo et al., 2024).

Game-Based Learning (GBL) is one promising approach for addressing these challenges. The approach embeds academic content into interactive and enjoyable activities, which allows it to create a motivating learning environment that encourages participation, collaboration, and critical thinking. In this instructional approach, learners acquire subject

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knowledge while developing emotional regulation, analytical skills, and social competencies such as teamwork and respect for rules (Farber, 2015; Johnson and Salter, 2022). Recent studies (Alt, 2023; Akman and Çakır, 2023; Chen and Tu, 2021; Hui and Mahmud, 2023; Hussein et al., 2022; İlhan, 2021; Vankúš, 2021) in mathematics education confirm that GBL can enhance student achievement, motivation, and satisfaction across various topics and grade levels. Based on these considerations, this study applied GBL to the concept of similarity in Grade 9 mathematics. Compare the students' achievements before and after the intervention, and explore their satisfaction with this innovative approach.

2. Literature review

Game-based learning (GBL) has deep historical roots. Ancient strategy games such as Chess and Mancala were used to cultivate reasoning, planning, and strategic thinking, long before the formal concept of educational gaming emerged (Hellerstedt and Mozelius, 2019). In classical antiquity, philosophers like Plato and Aristotle emphasized the importance of play in learning, linking it to both intellectual growth and moral development. The modern history of GBL began in the 20th century with the development of instructional games and early computer-based simulations. One of the first digital educational games demonstrated the potential of interactive technologies for learning. By the 1980s and 1990s, educational software and serious games gained popularity, coinciding with advances in microcomputers (Adams, 2014). In the 21st century, GBL expanded rapidly through the integration of digital platforms, mobile applications, and virtual environments, aligning game design with cognitive, motivational, and social dimensions of learning. This historical trajectory reflects the enduring recognition of play and games as powerful vehicles for education in both traditional and modern contexts.

The effectiveness of game-based learning is grounded in well-established educational theories. From a constructivist perspective, learners actively construct knowledge through interaction with their environment and peers. Games provide problem-based scenarios and immediate feedback, allowing learners to test hypotheses, adjust strategies, and integrate new knowledge with prior understanding (Hu, 2024). This experiential process aligns with constructivist views that meaningful learning occurs when students engage directly with content (Vygotsky, 1978).

Motivational frameworks, particularly Self-Determination Theory (SDT), also illuminate the value of GBL (Gupta and Goyal, 2022). According to SDT, intrinsic motivation flourishes when learners experience autonomy, competence, and relatedness (Deci and Ryan, 1985). Games are uniquely suited to satisfy these needs by offering choice, progressively challenging tasks, and opportunities for collaboration or competition with peers (Gupta and Goyal, 2022). This motivational support helps sustain engagement in subjects like mathematics that students may otherwise find difficult or intimidating.

Finally, Flow Theory underscores the psychological conditions that make GBL effective (Su and Hsaio, 2015). Flow occurs when the balance between challenge and skill creates a state of deep concentration, enjoyment, and immersion (Csikszentmihalyi, 1990). Well-designed games scaffold difficulty, provide immediate feedback, and offer achievable goals, helping students remain in the "flow zone." This state can enhance motivation and retention. Moreover, it stimulates the transfer of mathematical concepts to new situations.

Recent systematic reviews highlight the growing body of evidence on the effectiveness of game-based learning (GBL) in mathematics education. Hui and Mahmud (2023) synthesized 28 studies from 2018–2022 and concluded that GBL positively influences both cognitive and affective domains, particularly knowledge, mathematical skills, achievement, motivation, interest, and engagement. Similarly, Hussein et al. (2022), in their review of 43 articles from 2008–2019, reported consistent gains in knowledge acquisition, perceptual and cognitive skills, and affective outcomes. These findings confirm that GBL not only supports the mastery of mathematical content but also strengthens students' emotional and motivational orientation toward learning mathematics. However, both reviews pointed out gaps, especially the limited exploration of twenty-first-century competencies such as creativity and critical thinking, and the need for closer analysis of collaborative versus competitive dynamics in game design.

Complementing these reviews, Vankúš (2021) focused specifically on the affective dimension, analyzing 57 articles and noting that over half explicitly measured motivation, engagement, attitudes, and enjoyment. The majority of these studies (84%) reported positive effects, though some inconsistencies emerged due to limitations in research design, sample selection, or game quality. Primary studies further clarify how design matters. For instance, Alt (2023) demonstrated that problem-based gamification produced stronger gameful experiences and motivation than non-problem-based formats, while Chen and Tu (2021) confirmed the mediating role of self-efficacy and motivation under Social Cognitive Theory, underscoring the importance of feedback and social support. Likewise, İlhan (2021) found that although modeling-based activities generated the highest achievement in elementary geometry, GBL still outperformed conventional instruction in motivation and learning outcomes.

Emerging technologies also broaden the scope of GBL applications. Akman and Çakır (2023) showed that a virtual reality mathematics game improved primary students' achievement in fractions and enhanced social engagement compared to traditional mobile applications. Together, these studies indicate that GBL is effective when pedagogically aligned, problem-oriented, and supported by well-designed feedback mechanisms. At the same time, inconsistent findings highlight the need for rigorous research that clearly maps game mechanics to mathematical objectives and validates instruments for both cognitive and affective measurement. This body of evidence supports the relevance of investigating GBL in underexplored domains such as secondary geometry, particularly the concept of similarity, where students often face conceptual difficulties and low engagement.

Despite the strong evidence base, several gaps remain in the literature on game-based learning in mathematics. Prior reviews emphasize that most studies concentrate on primary-level arithmetic and basic operations (Hussein et al., 2022), with far less attention to secondary-level geometry concepts such as similarity, which are conceptually demanding and frequently misunderstood by learners. Moreover, inconsistent findings linked to weak game design, instrument validity, or a lack of problem orientation suggest that further research is needed to examine how carefully structured GBL interventions can support both cognitive and affective outcomes (Vankúš, 2021; Alt, 2023). Addressing these gaps, the present study aims to develop and evaluate a set of game-based lesson plans on the concept of similarity for Grade 9 mathematics students. Specifically, the study compares students' achievements before and after engaging in Game-Based Learning (GBL) and evaluates their satisfaction with the approach.

3. Method

This study employed a quasi-experimental design with a one-group pretest–posttest format. The design was chosen to examine the effects of game-based learning (GBL) on students' achievement and satisfaction with game-based learning, specifically regarding similarity. This approach enabled the researchers to evaluate learning gains and affective responses after the intervention (Table 1).

Table 1: Research design

Phase	Activity	Instrument
Before	Pretest	Achievement test
During	Game-based learning (9 lesson plans)	Various games (Math Error Hunt, Bingo, etc.)
After	Posttest	Achievement test + satisfaction questionnaire

The population consisted of 12 rooms; overall, 149 Grade 9 students were enrolled at Triam Udomsuksa Pattanakan Roi Et School, under the Roi Et Secondary Educational Service Area, during the semester of the 2024 academic year. The sample was random through cluster random sampling and included 11 students from Grade 9/2. These students were chosen to represent learners who typically faced challenges in mathematics achievement, particularly in geometry, thereby making them suitable for the intervention.

Nine lesson plans on the concept of similarity were developed using game-based learning. Each plan lasted one hour and was validated by experts for appropriateness; it is at the highest level of suitability in all plans (mean = 4.49 and 4.74), indicating high to very high suitability. The sequence of plans covered three units: (1) similar geometric figures (3 hours), (2) similar triangles (3 hours), and (3) problem-solving with similar triangles (3 hours). The game used Math Error Hunt, Math Snakes and Ladders Game, Math Quiz Challenge, Matching, Spot the Difference Game, and Math Bingo Game. And game platforms used included Vonder Go, Gimkit, Blooket, and Kahoot.

For example, in the lesson "Similar Triangles," students were introduced to the concept of corresponding angles and proportional sides. After a brief explanation, they played the Math Quiz Challenge. The steps are: The teacher has the students divide into groups, clarify the style of play, and then have the students answer questions on Blooket. They were asked to determine whether given pairs of triangles were similar, identify missing angle measures, and solve for side lengths using ratios. Immediate feedback from the game allowed students to correct misconceptions, while the competitive format motivated them to remain attentive.

Student mathematics achievement was measured using a teacher-developed test with 20 multiple-choice items (1 point each) and 5 constructed-response items (2 points each), totaling 30 points. All items showed acceptable validity (IOC > 0.50). The multiple-choice items had difficulty (P) = 0.38–0.75, discrimination (B-index) = 0.22–0.73, and reliability (Lovette) = 0.84. The essay test was analyzed using the formula proposed by Whitney and Sabers (1970). The results indicated item difficulty (P) = 0.53-0.69 and discrimination (D) = 0.25-0.63, and reliability (Cronbach's α coefficient) = 0.77.

Students' satisfaction with the GBL approach was assessed using a 15-item Likert-type questionnaire with five response options ranging from strongly disagree (1) to strongly agree (5). Content validity was confirmed with IOC values of 1.00.

Data collection proceeded in three phases. In the pre-experimental phase, students completed the pretest with an achievement test and were introduced to the procedures. During the experimental phase, the nine GBL lesson plans were implemented, and students engaged in the planned activities. In the post-experimental phase, students completed the posttest, which included the achievement test, the same pretest, and the satisfaction questionnaire.

Data were analyzed using percentage, descriptive, and inferential statistics. Satisfaction data were analyzed using means and standard deviations. Pretest and posttest achievement scores were compared using the Wilcoxon Signed Ranks Test, and Effect size by rank-biserial correlation (r) (Rosenthal, 1991):

$$r = \frac{Z}{\sqrt{N}}$$

where, Z is the standardized test statistic, and N is the number of observed pairs.

4. Results

The decision on statistical selection was based on examining the Tests of Normality and considering the sample size. The researcher tested the normality of the data distribution using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The results indicated that the pretest scores were not normally distributed ($p < 0.05$) (Table 2). In addition, given the small sample size ($n = 11$), the Wilcoxon Signed-Rank Test was selected for data analysis.

4.1. The comparison between learning achievement post-test and pre-test

In Table 3, the difference in learning achievement before and after instruction was analyzed using the Wilcoxon Signed Ranks Test. This non-parametric statistical method is appropriate for small samples and does not require the assumption of normal distribution. The analysis compared students' pretest and posttest scores on the similarity unit. Results showed that the mean pretest score ($\bar{X}$ = 5.27, SD = 2.72) was significantly lower than the mean posttest score ($\bar{X}$ = 23.09, SD = 1.30). The obtained Z value of 2.95 with a significance level of 0.00 ($p < 0.05$) indicates a statistically significant difference.

This means that after participating in the nine game-based learning lesson plans, students' achievement in mathematics on the topic of similarity improved substantially compared with their performance before the intervention. The effect size (r) is 0.89; using the rank-biserial correlation, this value represents a substantial effect size according to established criteria, indicating a strong positive impact of game-based learning on participants' achievement.

4.2. The student satisfaction with the game-based learning

The results of the student satisfaction survey indicated that Grade 9 students were satisfied with the game-based learning lesson plans on similarity at the highest level overall ($\bar{X}$=4.73, SD=0.19). When considering each item, fourteen of the indicators were rated at the highest level, and one item was rated at a high level. The highest mean score was for the statement "I am happy while participating in game-based learning activities" ($\bar{X}$ = 5.00, SD = 0.00). This was followed by items such as "I like the activities because they are easy to understand and modern," "The teacher's personality and appearance are appropriate," and "The time allocated for learning and activities is appropriate" ($\bar{X}$ = 4.91, SD = 0.30). Other highly rated items included "The teacher sequenced instruction from easy to difficult," "The activities made me enjoy and engage more with the lessons," "The activities encouraged me to share opinions with the teacher and classmates," and "I participated in discussion and summarization after each lesson" ($\bar{X}$ = 4.82) in Table 4. These results suggest that students not only benefited academically but also found the learning process enjoyable, engaging, and well-structured when taught through game-based learning.

Table 2: Tests of normality

Variable	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Prob	Statistic	df	Prob
pretest	0.267	11	0.027	0.903	11	0.201
post	0.164	11	0.200	0.934	11	0.448

Table 3: Comparison of pretest and posttest scores on similarity using game-based learning

Test	n	Total score	$\bar{X}$	SD	Paired differences $\bar{X}$	Paired differences SD	Z	Prob	Effect size (rank-biserial correlation (r))
Pretest	11	30	5.27	2.72	17.82	2.89	2.95	0.00*	0.89
Posttest	11	30	23.09	1.30					

*: prob < 0.05

Table 4: Participants' satisfaction with game-based learning

Item	$\bar{X}$	SD	Level
1. GBL made me more interested in learning	4.55	0.52	Highest
2. GBL encouraged me to think, act, and express myself	4.64	0.50	Highest
3. GBL helped me understand the content more clearly	4.55	0.52	Highest
4. GBL created a better classroom atmosphere	4.55	0.52	Highest
5. The introduction stimulated curiosity and inquiry	4.36	0.81	High
6. GBL allowed me freedom in learning	4.64	0.67	Highest
7. The teacher sequenced instruction from easy to difficult	4.82	0.60	Highest
8. Activities were easy to understand and modern	4.91	0.30	Highest
9. Activities made me enjoy and engage more with lessons	4.82	0.40	Highest
10. Activities encouraged me to share opinions	4.82	0.40	Highest
11. I was happy while doing GBL activities	5.00	0.00	Highest
12. The teacher's personality and appearance were appropriate	4.91	0.30	Highest
13. The teacher allowed questioning and sharing	4.73	0.47	Highest
14. I participated in the discussion and summarization	4.82	0.40	Highest
15. The allocated time was appropriate	4.91	0.30	Highest
Overall	4.73	0.19	Highest

5. Discussion

The comparison of pretest and posttest scores further confirmed that student achievement improved significantly after receiving instruction through GBL. The posttest scores were substantially higher than pretest scores, indicating that students developed a stronger understanding of similarity concepts after participating in the nine lesson plans. This aligns with findings by Vankúš (2021), who emphasized the positive effects of GBL on motivation and engagement, which in turn facilitate achievement. Moreover, Alt (2023) argued that problem-based game design is particularly effective in promoting student motivation and deep learning, a principle that was reflected in this study's use of problem-solving tasks within games such as Kahoot and Booklet. These outcomes are consistent with Hui and Mahmud (2023), who reported that GBL positively influences both cognitive and affective domains, and with Hussein et al. (2022), who found that GBL interventions yielded significant gains in knowledge acquisition and motivation.

The effectiveness of GBL in this study can also be explained through established learning theories. From a constructivist perspective, games provide active environments in which students test, adjust, and reorganize their knowledge rather than passively receiving information (Hu, 2024). The significant improvement in achievement suggests that students were not only memorizing formulas. It shows that they actively construct their understanding of similarity through interactive problem-solving. Self-Determination Theory further clarifies why GBL enhanced satisfaction: the activities allowed autonomy (choosing answers, working in teams), competence (progressive challenge, immediate feedback), and relatedness (peer competition and collaboration). These three conditions are well known to fuel intrinsic motivation, which was reflected in the very high satisfaction scores. Finally, the high engagement observed resonates with Flow Theory (Csikszentmihalyi, 1990), which posits that learning is optimized when the challenge of a task matches the learner's skill level. The carefully scaffolded games maintained this balance, creating a state of immersion that kept students focused and willing to persist with abstract geometry concepts.

In addition to achievement, students expressed very high levels of satisfaction with the lesson plans. The highest-rated items emphasized enjoyment, ease of learning, modernity of activities, and opportunities for participation. This finding echoes Chen and Tu (2021), who highlighted that self-efficacy and motivation act as mediating factors in digital GBL environments, particularly when social support and engaging feedback are present. Similarly, Akman and Çakır (2023) found that immersive GBL approaches foster engagement and positive attitudes in mathematics learning. Taken together, the present study provides further evidence that GBL not only enhances cognitive performance but also strengthens affective outcomes such as interest, enjoyment, and willingness to participate.

6. Conclusion

This study developed nine game-based learning lesson plans on the concept of similarity for Grade 9 mathematics, evaluated their efficiency, and examined students' achievement and satisfaction. The results indicated that the lesson plans achieved efficiency above the 75/75 criterion, students' posttest scores were significantly higher than their pretest scores, and overall satisfaction was at the highest level. The contribution of this study lies in demonstrating how game-based pedagogy can be systematically integrated into secondary mathematics instruction to enhance both cognitive and affective learning outcomes.

In terms of pedagogical implications, the findings suggest that incorporating game-based activities into mathematics instruction can make abstract concepts such as similarity more accessible, engaging, and meaningful for students. However, this study has several limitations. The sample size was relatively small ($n = 11$), which limits statistical power and constrains the generalizability of the findings. In addition, the absence of a control group prevents causal inferences regarding the effectiveness of the game-based learning intervention compared with traditional instruction. Furthermore, the study was conducted in a single school context. Future research should therefore employ larger and more diverse samples, adopt experimental or quasi-experimental designs with control or comparison groups, explore additional mathematical topics, and refine game design features to further enhance learning efficiency and student motivation.

List of abbreviations

B-index	Discrimination index (biserial index)
D	Discrimination index
df	Degrees of freedom
GBL	Game-based learning
IOC	Index of item-objective congruence
Lovette	Reliability coefficient (Lovette method)
N	Number of observed pairs
n	Number of samples
OBEC	Office of the Basic Education Commission
O-NET	Ordinary National Educational Test
P	Item difficulty index
p	Probability value (significance level)
Prob	Probability
r	Effect size (rank-biserial correlation coefficient)
SD	Standard deviation
SDT	Self-determination theory
$\bar{X}$	Mean (average value)
Z	Standardized test statistic

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Compliance with ethical standards

Ethical considerations

This study adhered to ethical standards for research involving human participants. As the participants were minors, informed consent was obtained from both the students and their parents or legal guardians prior to participation. Participation was entirely voluntary, and students were informed of their right to withdraw from the study at any time without penalty. All data were collected and reported anonymously to ensure participants' privacy and confidentiality.

Conflict of interest

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

References

Adams E (2014). Fundamentals of game design. Pearson Education, London, UK.

Akman E and Çakır R (2023). The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics. Interactive Learning Environments, 31(3): 1467-1484. https://doi.org/10.1080/10494820.2020.1841800

Alt D (2023). Assessing the benefits of gamification in mathematics for student gameful experience and gaming motivation. Computers & Education, 200: 104806. https://doi.org/10.1016/j.compedu.2023.104806

Chen CC and Tu HY (2021). The effect of digital game-based learning on learning motivation and performance under social cognitive theory and entrepreneurial thinking. Frontiers in Psychology, 12: 750711. https://doi.org/10.3389/fpsyg.2021.750711 **PMid:34975642 PMCid:PMC8716945**

Csikszentmihalyi M (1990). Flow: The psychology of optimal experience. Harper and Row, New York, USA.

Deci EL and Ryan RM (1985). Conceptualizations of intrinsic motivation and self-determination. In: Deci EL and Ryan RM (Eds.), Intrinsic motivation and self-determination in human behavior: 11-40. Springer, Boston, USA. https://doi.org/10.1007/978-1-4899-2271-7_2

Farber M (2015). Gamify your classroom: A field guide to game-based learning. Peter Lang, New York, USA. https://doi.org/10.3726/978-1-4539-1459-5

Greenwald S and Thomley J (2024). Mathematical similarity. EBSCO Information Services, Ipswich, USA. Available online at: https://www.ebsco.com/research-starters/physics/mathematical-similarity

Grigoriadou VJ, Coutelieris FA, and Theologou K (2021). History of the concept of similarity in natural sciences. Conatus - Journal of Philosophy, 6(1): 101-123. https://doi.org/10.12681/cjp.22955

Gupta P and Goyal P (2022). Is game-based pedagogy just a fad? A self-determination theory approach to gamification in higher education. International Journal of Educational Management, 36(3): 341-356. https://doi.org/10.1108/IJEM-04-2021-0126

Hellerstedt A and Mozelius P (2019). Game-based learning: A long history. In the Irish Conference on Game-based Learning, Cork, Ireland: 1-4.

Herbst P, Fujita T, Halverscheid S, and Weiss M (2017). The learning and teaching of geometry in secondary schools: A modeling perspective. 1st Edition, Routledge, London, UK. https://doi.org/10.4324/9781315267593

Hu Z (2024). Game-based learning: Alternative approaches to teaching and learning strategies in health sciences education. Educational Process: International Journal, 13(2): 90-104. https://doi.org/10.22521/edupij.2024.132.6

Hui HB and Mahmud MS (2023). Influence of game-based learning in mathematics education on the students' cognitive and affective domain: A systematic review. Frontiers in Psychology, 14: 1105806. https://doi.org/10.3389/fpsyg.2023.1105806 **PMid:37057144 PMCid:PMC10086333**

Hussein MH, Ow SH, Elaish MM, and Jensen EO (2022). Digital game-based learning in K-12 mathematics education: A systematic literature review. Education and Information Technologies, 27: 2859-2891. https://doi.org/10.1007/s10639-021-10721-x

İlhan A (2021). The impact of game-based, modeling, and collaborative learning methods on the achievements, motivations, and visual mathematical literacy perceptions. SAGE Open, 11(1). https://doi.org/10.1177/21582440211003567

Johnson EK and Salter A (2022). Playful pedagogy in the pandemic: Pivoting to game-based learning. 1st Edition, Routledge, London, UK. https://doi.org/10.4324/9781003281696

Jones K (2002). Issues in the teaching and learning of geometry. In Haggarty L (Ed.), Aspects of teaching secondary mathematics: Perspectives on practice: 121–139. 1st Edition, Routledge, London, UK.

Juman ZAMS, Mathavan M, Ambegedara AS, and Udagedara IG (2022). Difficulties in learning geometry component in mathematics and active-based learning methods to overcome the difficulties. Shanlax International Journal of Education, 10(2): 41-58. https://doi.org/10.34293/education.v10i2.4299

Rosenthal R (1991). Meta-analytic procedures for social research. SAGE Publications, Thousand Oaks, USA. https://doi.org/10.4135/9781412984997

Su C and Hsaio KC (2015). Developing and evaluating gamifying learning system by using flow-based model. Eurasia Journal of Mathematics, Science and Technology Education, 11(6): 1283-1306. https://doi.org/10.12973/eurasia.2015.1386a

Tiengyoo K, Sotaro S, and Thaithae S (2024). Exploring factors influencing 21st century mathematics in Thai secondary schools: A study in Lopburi Province. Pedagogical Research, 9(3): em0217. https://doi.org/10.29333/pr/14731 **PMid:26435059**

Ting GLC, Eng TH, Li LS, and Idris HBM (2023). A comparison study between active and passive students in intensive mathematics I course. Open Journal of Social Sciences, 11(5): 105-117. https://doi.org/10.4236/jss.2023.115009

Vankúš P (2021). Influence of game-based learning in mathematics education on students' affective domain: A systematic review. Mathematics, 9(9): 986. https://doi.org/10.3390/math9090986

Vygotsky LS (1978). Mind in society: The development of higher psychological processes. Harvard University Press, Cambridge, USA.

Whitney DR and Sabers DL (1970). Improving essay examination III: Use of item analysis. Technical Bulletin No. 11, University Evaluation and Examination Service, Iowa City, USA.