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iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 18 No. 7 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijim.v18i07.48067

PAPER

The Impact of Augmented Reality-Based Mathematics Learning Games on Students' Critical Thinking Skills

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ABSTRACT

The significance of critical thinking skills among students lies in their ability to actively assess, evaluate, and respond thoughtfully to information. This study investigates the impact of a game-based learning (GBL) model that utilizes augmented reality (AR) in mathematics learning games on the CT skills of eighth-grade junior high school students. The study specifically focuses on polyhedrons in mathematics. A quasi-experimental design was utilized to accomplish the study objectives. This study involved 77 students, divided into an experimental group of 40 students and a control group of 37 students. The research instrument used was a valid and reliable test of the students' CT skills. The results showed that the GBL model with AR-based games significantly improved students' CT skills. The students who received this approach showed more significant improvements in CT compared to traditional teaching methods. These results highlight the potential benefits of integrating AR technology into education to enhance students' CT skills. This encourages educators and curriculum developers to view AR as an effective alternative for supporting students' CT. The outcomes of this research indicate a significant advantage in using AR as a tool to promote CT among students. It could create more engaging and interactive learning environments.

KEYWORDS

critical thinking (CT) skills, game-based learning (GBL), polyhedrons, mathematics

1 INTRODUCTION

The evolution of technology and the global business landscape have heightened the demand for individuals to enhance their skill sets. These skills encompass problem-solving, critical thinking (CT), collaboration, creativity, communication, and adaptability, collectively known as the indispensable skills for thriving in the 21st-century professional realm [1–3]. CT can be developed through several effective strategies and guidance at all levels of education and disciplines [4]. One of the courses that can effectively develop students' CT skills is mathematics [5], [6]. It serves as a conduit for developing critical, analytical, systematic, logical, and CT skills.

Hanggara, Y., Qohar, A., Sukoriyanto. (2024). The Impact of Augmented Reality-Based Mathematics Learning Games on Students' Critical Thinking Skills. *International Journal of Interactive Mobile Technologies (iJIM)*, 18(7), pp. 173–187. https://doi.org/10.3991/ijim.v18i07.48067

Article submitted 2023-12-21. Revision uploaded 2024-02-11. Final acceptance 2024-02-12.

These diverse cognitive abilities are crucial for navigating life's challenges and opportunities [7]. It urges schools to cultivate CT skills among students through mathematics education. Despite this, the current process of learning mathematics fails to promote CT among students. It is not surprising that the CT skills among students were relatively low. Based on the study results of [8] to [10], students have poor CT skills. The teaching and learning process, which is typically teacher-centered and inhibits students from actively participating in the learning process, is the underlying cause of this issue [11], [12]. Teachers typically only demonstrate and discuss material in class [13], and the assessment of mathematical learning tends to concentrate solely on routine exercises and low-level questions [14]. Low students' CT skills can also be attributed to the teacher's tendency to solely request students to summarize, define, illustrate, and memorize, which could restrict the extent of their involvement and comprehension [15]. This is because students are not being asked to analyze, draw conclusions, connect, synthesize, criticize, create, evaluate, think, and rethink [16].

Based on these identified challenges, it is crucial to take proactive steps to improve students' CT skills. Students can be encouraged to think critically, logically, and systematically by utilizing active learning approaches. One effective approach is to employ the game-based learning (GBL) model using technology-based games. GBL has gained recognition as a valuable method to engage students in their learning journey, resulting in improved educational outcomes.

Numerous studies have explored the potential benefits of GBL in various educational settings. For instance, GBL can significantly improve learning outcomes, increase knowledge retention, and foster higher levels of student motivation and engagement [17–21]. The interactive and immersive nature of games allows learners to actively participate, solve problems, make decisions, and promote active learning and CT skills [22]. Additionally, GBL has been shown to create a positive and enjoyable learning environment, reduce anxiety, and alleviate stress often present in traditional classroom settings [23], [24]. These findings highlight the efficacy of GBL as an effective pedagogical tool that can revolutionize the way education is delivered in the 21st century.

Moreover, GBL has demonstrated its versatility in various subject areas and age groups. Regarding the area of science education [25], the impact of GBL on science revealed that it not only improves conceptual understanding but also facilitates the development of problem-solving and inquiry skills. These findings highlight the potential of GBL to cater to diverse learning needs and preferences, making it a valuable tool for teachers seeking to offer their students meaningful and effective learning experiences. The study introduces an innovative approach by combining the GBL model with AR technology. In contrast to traditional learning models, this research distinguishes itself by integrating structured gaming elements into the educational environment using GembiAR media. This innovative strategy enhances students' learning experiences through AR technology, with the goal of improving their CT skills. By introducing this new dimension, it strives to significantly enhance the effectiveness of education.

2 LITERATURE REVIEW

2.1 IT based learning

IT-based learning represents a contemporary educational approach that leverages information technology to enhance the learning journey. Rooted in educational theories such as constructivism and social constructivism, this method emphasizes learners' active involvement in constructing knowledge through interactions within the learning environment and among peers. Through a diverse range of digital tools and platforms, IT-based learning empowers students to access vast amounts of information, interact with dynamic multimedia resources, and engage in collaborative tasks. This multifaceted approach aims to cultivate a comprehensive understanding of the subject matter [26–28]. Moreover, the integration of gamification elements, virtual simulations, and personalized learning paths supported by learning analytics further motivates and empowers students to take charge of their learning journey [29–31]. Absolutely, as technology progresses, IT-based learning is poised to revolutionize conventional education by introducing greater flexibility, accessibility, and customization to cater to individual learning needs [32].

2.2 Game-based learning

Game-based learning is a type of instruction where learning is specifically assisted by the use of game apps [33], [34]. Indeed, GBL involves students engaging with specially designed games integrated into the educational context by teachers. This approach places learners at the center, harnessing the educational potential of games for effective learning [35]. The GBL process utilizes computer and smartphone games as a medium for conveying learning, enhancing understanding and knowledge skills, and evaluating materials for a discipline [35], [36]. GBL models can create a fun environment, boost motivation, and enhance creativity [37–39]. Therefore, GBL can be an interesting solution for students [40]. Games for learning often simulate scenarios that require CT and decision-making to overcome challenges. This interactive approach compels learners to strategize, problem-solve, and make decisions, fostering an engaging environment for effective learning [17], [41], [42]. Learning is dynamic and engaging when students play in an interactive manner, and this appeal persists as they work towards their objectives [43], [44]. Apart from the enjoyable and inspiring methods, GBL provides students with the opportunity to explore concepts in safe environments, learn through practice, and engage in social interactions with peers and their surroundings [45–47].

2.3 Critical thinking skills

In facing future challenges, students need to be prepared to overcome the problems they encounter [48]. The development of students' CT skills is crucial because, in the future, students will be required to solve increasingly complex everyday problems [49], [50]. Therefore, it is necessary to habituate students to use their CT skills in problem-solving.

Critical thinking is the ability to comprehend and analyze information objectively and systematically [51] and to interpret, predict, analyze, and evaluate [4]. It involves considering evidence, distinguishing between facts and opinions, and drawing logical and evidence-based conclusions [52]. CT skills are highly essential as they help individuals differentiate between useful and unreliable information, enabling them to make wise decisions based on reliable information. Moreover, CT is crucial in problem-solving and overcoming challenges [53]. It aids individuals in objectively and systematically understanding and analyzing problems and devising effective solutions supported by evidence [54]. CT is crucial for students as it allows them to delve into information, crucially assess it, and integrate diverse perspectives to arrive at informed conclusions. Numerous studies have emphasized the importance of fostering CT skills among students and have explored various methodologies to enhance these abilities.

Research by [55] underscores the importance of critical thinking in academic and real-world contexts. Facione emphasizes that CT skills contribute to effective decision-making, problem-solving, and communication, making them essential for students' success in various fields. In the educational context [56], the core components of CT include identifying arguments, assessing their validity, and drawing well-reasoned conclusions. Ennis emphasizes the importance of teachers in promoting CT by establishing an atmosphere that motivates students to question, analyze, and participate in intellectual discussions. Several studies have examined instructional strategies to promote CT. The concept of CT as a disciplined process involves intellectual standards such as clarity, accuracy, and relevance [57]. They advocate for incorporating Socratic questioning, where teachers guide students through thought-provoking questions to stimulate higher-order thinking. Technology also plays a significant role in enhancing CT skills [58]. Gamification and simulation-based learning have been shown to provide immersive experiences that require students to think critically in interactive and dynamic scenarios [59]. Furthermore, the use of AR technology in education has gained attention. AR combines digital information with the real world, providing unique opportunities to enhance CT skills. AR-based learning environments promote active engagement and problem-solving skills by overlaying digital content onto real-world contexts [60].

In conclusion, fostering students' CT skills is essential to their overall intellectual growth and achievement. This literature review emphasizes the importance of CT skills across different domains, explores teaching methods to enhance these skills, and recognizes the potential of technology, specifically AR, in developing engaging learning experiences that encourage students' CT. As education continues to evolve, nurturing CT remains a fundamental goal for educators and researchers alike.

3 RESEARCH OBJECTIVES

The main aim of this study is to assess how a GBL model, utilizing mathematics learning games supported by AR, influences the development of CT skills among students. This research investigates the effectiveness of the GBL method combined with AR technology in nurturing CT skills in students. The aim is to provide valuable insights into the benefits of combining GBL and AR in educational settings, especially in developing and improving students' CT skills.

4 METHODS

4.1 Research design

This quantitative study examines the impact of the GBL model with GembiAR on students' CT skills using a quasi-experimental design. There were two sets of subjects: experimental and control groups. The experimental class was provided with a GBL learning model using GembiAR as a treatment. The control group underwent conventional learning. Before applying various learning methods, the two classes were given a pre-test to assess their initial CT skills. The study design is presented in Table 1.

Table 1. Research design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control	O_1	X_2	O_2

Notes: O_1: Pretest; O_2: Posttest; X_1: Learning with the GBL model with GembiAR; X_2: Conventional Learning.

The game used in the GBL model is GembiAR. This game was developed to teach polyhedron concepts. This game consists of six missions that students must complete. The first mission is related to the definition of a polyhedron; the second mission involves the elements of a polyhedron; the third mission is about polyhedral nets; the fourth mission deals with surface area; the fifth mission is related to volume; and the sixth mission discusses the combined volume of a polyhedron. The GembiAR's appearance can be seen in Figure 1.

Fig. 1. The GembiAR model

Throughout the game, students will be shown visualizations of the three-dimensional forms of the shapes being studied. Students can manipulate the shapes in the missions by rotating, enlarging, and shrinking them. Additionally, students can listen to explanations related to the material being studied while playing the game. The game activity in GembiAR can be seen in Figure 2.

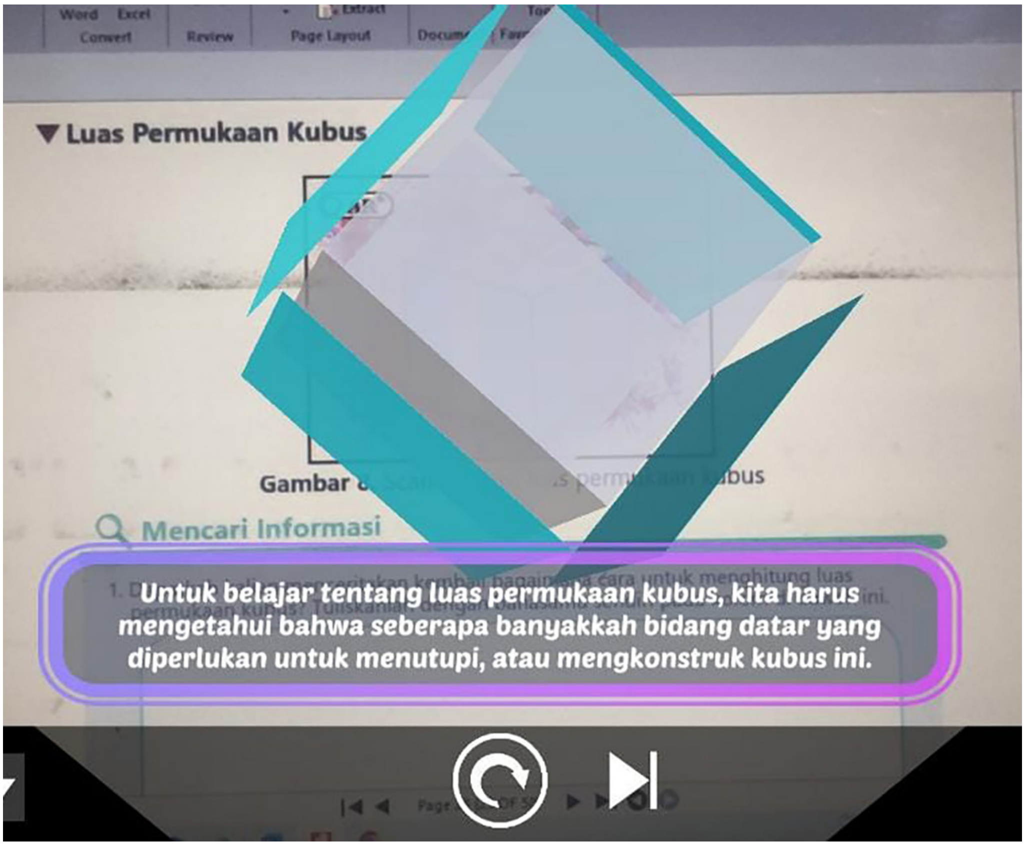

Fig. 2. Visualization of the GembiAR game

4.2 Participants

Seventy-seven students from State Junior High School 27 in Batam, Indonesia are involved in this study. The participants are divided into two groups: the control group, consisting of 37 students, and the experimental group, consisting of 40 students.

4.3 Data collection instrument

The data was collected using a CT skills test. The CT skills test instrument was developed based on indicators from a previous study [55]. The instrument used was validated by two experts. Furthermore, revisions have been made based on expert advice. After the instrument was deemed valid, it was tested with 30 students. Pearson's product-moment formula was used to determine the validity of the essay-format test. The three questions tested were declared valid with statistical significance. Values for the three questions are < 0.05. Afterward, the instrument's reliabilities were calculated using Cronbach's alpha formula, and they were found to be reliable with a reliability coefficient of 0.737.

4.4 Data analysis

In this study, SPSS was used for data analysis. The Levene test was used as a homogeneity test of variance, while the Kolmogorov-Smirnov test was employed to assess the normality assumption. After the data passed the prerequisite test, it was analyzed using parametric statistics. Two-tailed independent t-tests and N-Gain analyses were used to measure the effectiveness of the GBT model with GembiAR on students' CT skills. The following formula was used to calculate the N-Gain score [61]:

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{100 - Pretest\ Score} \tag{1}$$

Furthermore, the N-Gain score is categorized using the Meltzer category [62] presented in Table 2.

Table 2. N-gain score value category

N-gain Score	Category
N-gain ≥ 0.70	High
0.30 < N-gain < 0.70	Medium
N-gain ≤ 0.30	Low

5 RESULT

Before testing the hypothesis, it was necessary to perform normality tests for the pretest and posttest data. The results of the normality and homogeneity tests are presented in Tables 3 and 4.

Table 3. Results of the normality test for critical thinking skills

Class	Kolmogorov Smirnov Test			
	Data	Statistic	Df	P
Experiment	Pretest	0.116	39	0.191
	Posttest	0.121	39	0.147
Control	Pretest	0.110	36	0.200
	Posttest	0.116	36	0.200

Table 4. Homogeneity test results for critical thinking skills

Critical Thinking Skills				
	F	Df_1	Df_2	P
Pretest	0.214	1	75	0.645
Posttest	0.189	1	75	0.189

Prior to implementing the GBL learning model with GembiAR media and conventional learning, a pre-test was administered to assess the initial CT skills of both classes. The results of an independent two-sample t-test indicated no significant difference between the classes ($t = 1.099$, $p > 0.05$). This suggests that both classes exhibited similar levels of CT skills before the start of the learning model. Detailed t-test results are summarized in Table 5.

Table 5. T-test of 2 independent samples of initial critical thinking skills

		T-test for Equality of Means						
		T	df	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Critical thinking skills	Equal variances assumed	1.099	75	.275	2.65878	2.42033	2.16276	7.48033

The experimental class received GBL learning with GembiAR media, while the control class had conventional learning. The material was a polyhedron. Both classes had six sessions and a post-test to assess CT skills. Table 6 displays the data on students' CT skills after the various treatments.

Table 6. Data description of students' CT skills

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Pretest experiment	40	45.00	25.00	70.00	43.8750	11.12214	123.702
Posttest experiment	40	30.00	50.00	80.00	66.0007	7.44261	55.392
Pretest control	37	40.00	20.00	60.00	41.2162	10.02811	100.563
Posttest control	37	33.33	26.67	60.00	42.1622	8.68610	75.448

Based on Table 6, the implementation of the GBL learning model with GembiAR can enhance students' CT skills compared to traditional learning models. This can be seen from the increase in the average pre-test and post-test scores. The next analysis tested the effectiveness of the GBL model with GembiAR on students' CT skills. The effectiveness was tested using a t-test with two independent samples by comparing the average post-test scores of the experimental and control classes. The results of the t-test for the two independent samples are presented in Table 7.

Table 7. T-test results for two independent samples of CT skills

		T-test for Equality of Means						
		T	df	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Critical thinking skill	Equal variances assumed	12.961	75	.000	23.83859	1.83923	20.1746	27.5025

Based on Table 7, we can observe a significant difference between the post-test scores of the experimental and control classes ($t = 12.961$ and $p < 0.05$). Thus, it can be concluded that the GBL learning model with GembiAR is more effective than conventional learning models in enhancing students' CT skills. Furthermore, to assess the extent of improvement in CT skills in both the experimental and control classes, the N-gain test was utilized. The results of the N-gain test are listed in Table 8.

Table 8. N-gain test results for experimental class and control class

Class	N	Pretest	Posttest	N-Gain	Category
Experiment	40	43.8750	66.0007	0.3942	Medium
Control	37	41.2162	42.1622	0.0160	Low

Based on Table 8, we can observe an increase in students' CT skills in the experimental class within the moderate category. By contrast, in the low-category control class. This demonstrates that the GBL learning model with GembiAR can enhance students' CT skills more effectively than conventional learning models.

6 DISCUSSION

The findings suggest that the GBL model combined with GembiAR can enhance students' CT skills. In order to enhance their CT skills, students can regularly practice solving real-world problems using various strategies, receive feedback, analyze information, and make decisions using GBL with GembiAR. One of the strengths of GBL is its ability to provide direct feedback to students. In this way, students can evaluate their performance, analyze their mistakes, and develop CT. When students interact with the game and receive relevant feedback, they can refine their strategies, redesign them, and test new hypotheses. Thus, GBL can encourage students to think reflectively and hone their CT skills over time. This is in line with the opinions of [24], [43], [63], [64] who stated that a GBL approach can enhance student performance, attitudes, motivation, and CT skills compared to learning methods that do not incorporate games. By incorporating games into the learning process, students become highly motivated to learn. Motivation has a positive relationship with academic achievement [64]. Based on observations of the GBL learning process using GembiAR media, students were enthusiastic to participate during the learning activities. Students were eager to utilize GembiAR media in their learning activities, as shown in Figure 3.

Fig. 3. Learning activities with GembiAR

The GembiAR media used in the GBL model helps students understand the material more deeply than just listening to the teacher's explanation. The use of computer games for teaching helps students develop a positive attitude towards mathematics. Active participation in learning, particularly in subjects such as mathematics, often results in improved efficiency in the learning process. When students are actively engaged, they tend to comprehend mathematical concepts more thoroughly [38], [65–67]. The interactive nature of games in GembiAR exposes students to scenarios that require problem-solving, information analysis, decision-making, and the consideration of diverse perspectives. This active involvement encourages students to apply critical and creative thinking to achieve the objectives set within the game. Furthermore, the engaging and enjoyable learning experience offered by GembiAR can significantly contribute to the development of CT skills among students. An interactive and stimulating learning environment not only motivates students to participate actively but also encourages the cultivation of CT skills. Furthermore, teaching assisted by computer games can lead to much better learning outcomes compared to traditional methods [68], [69]. Computer games utilizing AR technology can yield superior learning outcomes compared to traditional games.

The amalgamation of the GBL model with AR technology stands out as a powerful approach to enhancing students' CT skills across various dimensions, as outlined by Facione's indicators. By engaging with interactive AR-based mathematics learning games, students immerse themselves in deciphering complex scenarios, analyzing information within augmented contexts, evaluating options, predicting outcomes, articulating strategies, refining problem-solving capabilities, and enhancing decision-making skills. The dynamic fusion of real-world and digital elements in these games nurtures every aspect of CT, empowering students to unravel intricate systems, make informed decisions, and articulate coherent reasoning. This comprehensive preparation equips individuals to excel in both academic and practical contexts.

Moreover, the GBL model's integration of AR-based games surpasses traditional teaching methods by providing an immersive and experiential learning environment. This approach not only captures students' attention but also enables them to apply CT skills in real-time decision-making scenarios. As students navigate these augmented worlds, they are prompted to assess, analyze, and synthesize information from multiple sources, mirroring the complexity of real-world challenges. By engaging with digital overlays in their physical surroundings, students develop a deeper understanding of context and relationships, thereby enhancing their CT abilities. This synergy between GBL and AR presents an innovative pathway to nurturing multifaceted CT skills essential for thriving in the rapidly evolving landscape of education and beyond.

7 CONCLUSION

The outcomes highlighted the efficacy of integrated GBL learning with GembiAR in enhancing students' CT skills. Those exposed to this combined approach exhibited significant advancements in problem recognition, data gathering and analysis, appraisal of alternatives, and decision-making skills. The integration of GBL and GembiAR not only increased student engagement but also strengthened the learning process. The interactive nature of GembiAR's gaming modules enriched the educational experience and contributed to enhancing CT skills. These findings underscore the transformative potential of integrating technology-enhanced GBL methods, such as GembiAR, in reshaping education. They demonstrate the capacity of these innovative tools to actively develop a variety of CT skills in a promising and engaging manner.

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