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# Effectiveness of Game-Based Learning in Enhancing Anatomy Academic Performance of Gen Z Preclinical Medical Students

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## ABSTRACT

Anatomy is often perceived as a difficult subject by preclinical medical students. Game-based learning (GBL) offers an interactive approach that can enhance motivation and engagement, particularly among Generation Z (Gen Z) learners. This study aimed to determine the effectiveness of GBL in improving anatomy academic performance among first-year medical students compared with traditional learning. A quasi-experimental pretest-posttest control-group design was used, with the intervention group (receiving an anatomy lesson supplemented with Kahoot!-based game quizzes) and the control group (without Kahoot!-based game quizzes). Posttests were administered to both groups at the end of the session. Validated pretest and posttest questions were administered to both groups. Data were analysed using N-gain scores and the Mann-Whitney U test. Students' perceptions of GBL were explored through thematic analysis of open-ended responses. From a total of 227 participants, the intervention group (n = 112) showed a significantly higher mean N-gain score (75.53%), indicating moderate effectiveness (55% < N Gain ≤ 76%) than the control group (n = 115) (45.21%) ($p < 0.001$), with a large effect size (d = 2.76). Students reported that GBL created an enjoyable, competitive, and motivating learning experience that enhanced participation and self-reflection. However, they also noted challenges such as unstable internet connectivity and limited time during sessions. Therefore, GBL, paired with traditional learning, significantly enhances academic performance. These findings support integrating GBL into anatomy curricula to improve learning outcomes for Gen Z students.

**Keywords:** *Effectiveness, Game-based learning, Academic performance, Generation Z students, Anatomy teaching*

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## INTRODUCTION

It is critical to consider generational differences when designing effective teaching strategies (1). A generation comprises individuals with similar characteristics and perspectives shaped by the events and developments of their formative years, which influence their attitudes and behaviour. These traits tend to remain stable over time and distinguish one generation from another (1). The Gen Z cohort, born between 1995 and 2010, grew up in an era of rapid technological advancement, which set them apart as the digital generation (2,3). According to the 2022 population census conducted by the Central Statistics Agency of Indonesia, 89.27 million individuals belong to this generation in the country, thereby accounting for 32.73% of the national population (2,3). The creative and competitive nature of Gen Z individuals calls for teaching methods that are dynamic and tailored to their unique strengths (3,4). This principle is particularly relevant in medical education, which involves rigorous academic and professional training in both basic medical sciences and clinical practice (5).

Anatomy, a foundational discipline in medical education, presents unique challenges. Students often find it difficult due to the need to memorise extensive anatomical terms, many of which are in Latin (6). Additional difficulties include identifying anatomical structures, integrating anatomy with clinical sciences, and limited access to cadaver-based learning. Commonly utilised traditional learning methods in anatomy include lectures by experts, reading textbooks, studying anatomical atlases, and cadaver dissection (7).

Interactive online quizzes provide a potential solution to these challenges (7). Administering quizzes at the beginning of anatomy lessons can enhance students' academic performance, as demonstrated by improved posttest scores across learning topics (8). Moreover, engaging and interactive quizzes can foster students' curiosity, motivation, and participation. This method can be more effective if the format, content, and difficulty level of the questions are tailored to the students' needs and learning objectives (9).

Game-based learning (GBL) is a digital teaching approach that encourages student engagement and academic achievement, thus making it particularly appealing to Gen Z preclinical medical students (10,11). It aligns well with constructivist learning theory. This theory posits that learners actively construct knowledge through experience and interaction rather than by passively receiving information. Learners select and revise information acquired from past experiences to develop new knowledge and continuously test their comprehension in response to novel situations. When new information conflicts with their current mental models, they adjust their understanding to integrate and accommodate these new experiences (12,13).

This process involves reflection, feedback, and adaptation, thereby enabling learners to develop deeper conceptual understanding through continuous engagement with their environment. GBL reflects these constructivist principles by immersing students in experiential, interactive environments. In GBL, learners make decisions, receive immediate feedback, and refine their understanding through repeated engagement. This process promotes autonomy, critical thinking, and problem-solving—key components of constructivist learning. Moreover, many educational games encourage collaboration and communication, thus aligning with Vygotsky's social constructivism, which emphasises learning through social interaction (12,13). By integrating these theoretical foundations, GBL creates dynamic and adaptive learning experiences that mirror real-life problem-solving. This transforms the learning process into an active cycle of exploration, feedback, and reflection, thus enabling medical students to develop lasting and meaningful knowledge (a deep understanding of concepts that enables learners to integrate new information with

prior knowledge and apply it effectively in relevant contexts). Consequently, GBL serves not only as an instructional strategy but also as an application of constructivist learning principles in medical education (12,13).

Shofyana et al. (14) reported that GBL's standout attribute lies in its capacity to accommodate a wide spectrum of learning needs and preferences, thereby addressing a common shortfall of traditional instruction. Therefore, it creates a flexible, adaptive environment in which individual students can participate at their own pace and with their own strengths. Indonesia has a rather strong collectivist culture. This collectivist culture strengthens relationships among students and between students and teachers, thereby enhancing academic achievement.

The application of GBL in professional health education has significantly expanded over the past decade, particularly with advances in digital learning technologies (15). Felszeghy et al. (16) reported its effectiveness in improving knowledge retention, motivation, critical thinking, decision-making, and academic performance in histology instruction (16). However, despite its growing use, empirical evidence of its impact on academic performance is limited, specifically among Gen Z medical students learning anatomy in Southeast Asia. This study investigated whether the academic performance of first-year medical students learning anatomy is better using GBL as compared to traditional methods.

## METHODS

### Research Design

To analyse the effectiveness of GBL in enhancing the academic performance of Gen Z preclinical medical students in anatomy, a quasi-experimental study was conducted using a pretest–posttest control group design. This design was selected to enable group comparison while preserving ecological validity, as the random allocation of students was not feasible due to class structure and ethical constraints.

### Research Subjects

The minimum sample size was calculated using a two-sided unpaired numerical comparison formula (independent samples t-test). The calculation assumed an α error probability of 0.05, a statistical power (1–β) of 0.80, and a moderate effect size (Cohen's d = 0.5), which was selected as a conservative estimate based on prior educational intervention studies. The sample size estimation was performed using GPower software version 3.1.9.7 (Heinrich Heine University Düsseldorf, Germany), thus resulting in a minimum required sample of 70 participants. Total sampling was applied to include all eligible first-year medical students enrolled in anatomy laboratory classes at the preclinical medical school of Universitas Andalas, Indonesia, between February 2024 and May 2024. The final sample comprised 227 students, with 112 assigned to the intervention group and 115 to the control group.

### Game-Based Learning

GBL is an instructional approach that utilises digital platforms to promote interactive, student-centred learning. In this study, the GBL intervention was implemented through

Kahoot!, a web-based game platform that supports real-time formative assessment, instant feedback, and competitive engagement. Kahoot! was selected because it is widely accessible, compatible with mobile devices, and has been validated in previous medical education studies for improving motivation, participation, and knowledge retention (15). Compared with other platforms such as Quizizz, Socrative, or Mentimeter, Kahoot! provides an intuitive interface suitable for large classroom settings, supports immediate performance ranking, and facilitates structured debriefing after each game round—features that align well with the reflective feedback cycle of constructivist learning (17). The implementation of GBL was divided into four phases, as presented in Table 1.

**Table 1:** The implementation of GBL

| Phase | Activity | Duration (minutes) |
|---|---|---|
| I | Introduction and explanation of the game's purpose and concept | 3 |
| II | Explanation of the game rules | 2 |
| III | The game begins, and an explanation of the material is provided by the standardised teaching staff according to the questions presented | 15 |
| IV | Student reflection | 5 |

## Data Collection Procedure

The intended learning outcome, based on Bloom's taxonomy, was for the students to demonstrate understanding of the anatomical concepts in Block 1.4—specifically the metabolism of the abdominal wall and the digestive system. At the beginning of the study, a pretest comprising validated multiple-choice questions (MCQs) was administered to both groups to assess baseline knowledge. Thereafter, a GBL quiz was administered to the students in the intervention group using Kahoot! platform. The quiz consisted of four sessions, each with five questions that differed from those in the pretest. The questions were discussed after all the students had completed the quiz. Following this GBL activity, the students in the intervention group continued their learning using traditional learning methods. In contrast, after the students in the control group completed the pretest, they continued learning solely utilising traditional learning methods.

The GBL programme was conducted over six weeks (February 2024–May 2024), with one session per week integrated into the regular anatomy schedule. Upon completion of the final GBL session, a posttest—identical in format to the pretest and comprising MCQs—was administered to both groups to evaluate academic performance.

Following the posttest, a perception survey was distributed to the intervention group via Google Forms to elicit students' reflections on the GBL experience. The survey was conducted after the posttest to capture students' comprehensive impressions of the intervention without influencing their test performance. The survey link was shared through the official student group chat and announced by the lecturer at the end of the final GBL session. To encourage participation, two reminders were sent within one week after the initial distribution. Participation was voluntary, and anonymity was ensured to maintain the authenticity and confidentiality of responses.

### Research Instrument

The pretest and posttest instruments consisted of 20 validated multiple-choice questions (10 questions on the abdominal wall and 10 on the digestive system). Five expert anatomy lecturers first reviewed the items and then pilot-tested on 30 second-year medical students, who were comparable to the study group in terms of age, curriculum exposure, and learning context (i.e., Gen Z preclinical students within the same institution).

For content validity, items with correlation coefficients above $r = 0.306$ (based on the sample size at $\alpha = 0.05$) were considered valid. Reliability testing using Cronbach's $\alpha = 0.755$ indicated acceptable internal consistency, thus exceeding the commonly accepted threshold of 0.70 for educational assessment instruments. The difficulty index (P) was categorised as easy ($0.7 < P \leq 1.0$), moderate ($0.3 < P \leq 0.7$), and difficult ($0 < P \leq 0.3$), while the discrimination index (D) ranged from low ($0 < D \leq 0.2$) to moderate ($0.2 < D \leq 0.4$).

### Analysis Method

The data were first tested for normality using the Kolmogorov–Smirnov test. This was followed by Levene's test for homogeneity of variances to determine whether the groups had equal variances. As the data were not normally distributed, the analysis was conducted using the Mann–Whitney U test in SPSS version 27. To measure the effectiveness of the GBL method in improving students' academic performance, the normalised gain (*N*-gain) test was employed. The *N*-gain scores were interpreted in the following manner: *N*-gain < 40% signified ineffectiveness; 40% ≤ *N*-gain ≤ 55% signified low effectiveness; 55% < *N*-gain ≤ 76% signified moderate effectiveness; and *N*-gain > 76% signified high effectiveness. The Mann–Whitney U test was again employed to determine the effectiveness of GBL on academic performance, with significance established at $p < 0.05$ using two-tailed testing. The effect size was calculated using Cohen's *d*, interpreted in the following manner: 0.2 = small effect; 0.5 = medium effect; 0.8 = large effect; and > 2 = very large effect.

Thematic analysis was conducted to evaluate students' perceptions of the GBL implementation. The analysis followed Braun and Clarke's six-phase framework: familiarisation with the data, generating initial codes, identifying themes, reviewing themes, defining and naming themes, and producing the final report. Coding was inductively conducted, thus enabling themes to directly emerge from the responses. Two independent researchers read all transcripts, collaboratively developed an initial codebook, and then separately applied the codes. Intercoder reliability was calculated using Holsti's formula on approximately 20% of the data, and discrepancies were discussed until consensus was achieved. To enhance trustworthiness, both method and data-source triangulation were employed, comparing interview data with field notes and supporting documents via Google Forms. Themes and subthemes were finalised based on code frequency and conceptual coherence.

## RESULTS

### Characteristics of the Research Respondents

In both groups, study respondents were predominantly female, with the most common age group at 19 years. The mean Grade Point Average (GPA) was 2.61 in the intervention group

and 2.81 in the control group, indicating no statistically significant difference between the groups. These comparable baseline characteristics among the groups in gender, age, and GPA suggest initial group equivalence (Table 2).

**Table 2:** Characteristics of the research respondents

| Characteristic | Intervention group (n = 112) | Mean | Control group (n = 115) | Mean |
|---|---|---|---|---|
| Gender | | | | |
| Male | 34 (30.4) | | 34 (29.5) | |
| Female | 78 (69.6) | | 81 (70.4) | |
| Age | | | | |
| 17 years old | 5 (4.5) | | 10 (8.7) | |
| 18 years old | 51 (45.5) | | 45 (39.1) | |
| 19 years old | 52 (46.4) | | 48 (41.7) | |
| 20 years old | 4 (3.6) | | 12 (10.4) | |
| GPA score | | | | |
| ≥ 3.5 – 4.0 | 26 (23.2) | 2.61 ± 1.04 | 31 (27.0) | 2.81 ± 1.03 |
| ≥ 3.0 – < 3.5 | 29 (25.9) | | 43 (37.4) | |
| ≥ 2.5 – < 3.0 | 12 (10.7) | | 12 (10.4) | |
| ≥ 0.0 – < 2.5 | 45 (40.2) | | 29 (25.2) | |

Note: Data are presented as numbers (%) unless otherwise stated.

## Analysis of the Effectiveness of the GBL Method

The results of the *N*-gain test are presented in Table 3. The pretest mean score of the intervention group is 51.79 ± 5.81, and that of the control group is 52.26 ± 5.75 ($p = 0.536$). The average *N*-gain score for the intervention group is 75.63%, thus indicating moderate effectiveness. In contrast, the control group achieved an average *N*-gain score of 45.21%, which reflected low effectiveness. The significance test revealed a statistically significant result ($p < 0.001$). The observed effect size was rather large, with a Cohen's d value of 2.76.

**Table 3:** GBL method's effectiveness

| Item assessment | Intervention group (n = 112) | | | Control group (n = 115) | | | *p*-value | Cohen's d |
|---|---|---|---|---|---|---|---|---|
| | Minimum point total (%) | Maximum point total (%) | Average point total ± SD | Minimum point total (%) | Maximum point total (%) | Average point total ± SD | | |
| Pretest | 40 (5.4) | 65 (0.9) | 51.79 ± 5.807 | 40 (7.8) | 65 (0.9) | 52.26 ± 5.745 | 0.536 | – |
| Posttest | 75 (0.9) | 100 (3.6) | 88.35 ± 5.344 | 65 (0.9) | 85 (6.1) | 73.96 ± 5.319 | – | – |
| N-Gain ± SD | 75.637 ± 11.368 (Moderate effective) | | | 45.211 ± 10.641 Low effective) | | | < 0.001 | 2.76 |

Notes: Data are presented as mean ± standard deviation unless otherwise stated; N-Gain = to measure the effectiveness of the GBL method Mann-Whitney test = to analyse the effectiveness of the GBL method.

## The Relationship of the N-gain Score with Age, Gender, and GPA

In this study, no trend favouring either gender or age group was observed. However, the relationship between the *N*-gain score and GPA was significant, as shown in Table 4.

**Table 4:** The relationship of N-gain score with age, gender, and GPA

| Characteristic | Average N-Gain score | *p*-value |
|---|---|---|
| Gender | | |
| Male | 50.99 | 0.234 |
| Female | 58.90 | |
| Age | | |
| 17 years old | 87.30 | 0.113 |
| 18 years old | 53.43 | |
| 19 years old | 55.36 | |
| 20 years old | 72.00 | |
| GPA score | | |
| ≥ 3.5 – 4.0 | 45.79 | 0.002 |
| ≥ 3.0 – < 3.5 | 42.88 | |
| ≥ 2.5 – < 3.0 | 65.24 | |
| ≥ 0.0 – < 2.5 | 71.58 | |

Note: Mann-Whitney test = to analyse the effectiveness of the GBL method

## Students' Perceptions of the GBL Method

Thirty-one students voluntarily provided responses about their experiences with the GBL method, representing approximately 27.7% of the intervention group (n = 112). While the relatively small proportion of respondents may limit the generalisability of these qualitative findings, the collected data still provide meaningful insights into the students' perceptions. Efforts such as verbal reminders and online announcements were made to encourage participation, although responses remained voluntary. The feedback from these participants highlighted both the advantages and challenges of implementing GBL in anatomy learning.

The application of the GBL method in teaching anatomy demonstrated several advantages. The results of the students' perceptions revealed that the GBL method was enjoyable and fostered a sense of competition among participants. One participant noted,

> As young people, we often had a desire to compete in a game. We felt that seeing the role/character we used in a game in the top position was enjoyable. That is why we often played using aliases. In short, learning with this method was enjoyable. By playing, we became more competitive, and when we made mistakes, it was easier for us to remember which parts we still needed to study. (M6)

The participants' responses to the perception survey were analysed using thematic analysis, following Braun and Clarke's six-phase framework that includes familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report.

This method was an innovative approach to teaching anatomy and made the learning process more engaging and enhanced the students' enthusiasm: "It was enjoyable and represents an innovation in anatomy practical activities" (M5). The students also believed that the GBL method could serve as a tool for self-reflection regarding the material to be learned. One student noted,

> It allowed us to understand the overview of anatomy lessons before starting the practical sessions. If there were any incorrect answers while playing Kahoot!, we could immediately look for the correct answers during the practical, which helped us remember better. (M13)

However, during the implementation, several students encountered challenges that hindered the application of the GBL method. The most significant obstacles experienced were related to internet access and limited time allocation. For example, one participant stated, "It was very good, but it might have been less effective due to the network issues" (M22). Another added, "Limited time and unstable internet signal" (M27). Thematic analysis revealed two overarching themes with several subthemes related to students' perceptions of the GBL implementation (Table 5).

**Table 5:** Thematic analysis

| Theme | Sub-theme |
|---|---|
| Advantages of implementing the GBL method | • Fun method<br>• Boosts competitive spirit<br>• An innovation<br>• Serves as self-reflection<br>• Helps understand the material |
| Challenges in implementing GBL | • Unstable internet access<br>• Limited time allocation |

## DISCUSSION

This study revealed that GBL significantly enhanced the academic performance in anatomy of the participating Gen Z preclinical medical students. The average *N*-gain score in the intervention group (75.53%) was significantly higher than that in the control group ($p < 0.001$), thereby indicating moderate effectiveness, while Cohen's d value of 2.76 reflects a rather large effect. Although a moderate effect size was assumed during the sample size calculation, the observed Cohen's d value indicates a substantially larger effect, thus suggesting that the intervention had a stronger impact than initially anticipated. These findings align with those of previous studies. Maulida et al. (18) reported improved student outcomes after applying GBL, with an *N*-gain score of 65%, also indicating moderate effectiveness. Similarly, Garza et al. (19) observed significant improvements in students' neuroanatomy exam scores and final grades after they engaged in GBL on the Kahoot! platform.

The validity and reliability of the test instruments in this study were satisfactory (Cronbach's $\alpha = 0.755$), thus confirming that the tools appropriately measured students' learning outcomes. The difficulty and discrimination indices of the test items were within the acceptable range, thereby supporting the robustness of the quantitative findings. Furthermore, the pretest mean scores between the intervention and control groups were not significantly different ($p = 0.536$), thus demonstrating initial group equivalence in academic ability, Similarly, Sana et al. (20) found that administering pretests serves a dual function: assessing students' baseline understanding while simultaneously boosting their motivation to learn.

Further analysis revealed that the *N*-gain scores were significantly associated with GPA but not with age or gender (Table 4). Consistent with a previous study by Alifa et al. (17), this finding suggests that academic achievement among medical students is more strongly influenced by mastery of the subject matter than by demographic factors such as age, gender, and socioeconomic background. In other words, GBL appears to benefit students equally across genders and age groups, while those with higher academic readiness or prior achievement, as reflected in GPA, may gain a greater advantage from the interactive, feedback-driven learning environment (17,21).

The posttest results showed that the intervention group achieved significantly higher scores after GBL sessions than the control group, which relied solely on traditional cadaver-based instruction. This indicates that GBL enhances knowledge retention and reinforces learning, which is in line with the findings of Cortés-Pérez et al. (22), who reported that GBL activities using Kahoot! Quizzes and reward cards significantly improved academic scores and engagement among physiotherapy students.

Qualitative findings further support the quantitative results. Although the response rate was relatively low, the obtained feedback still provided valuable insights into students' experiences and perceptions of the GBL intervention. The limited participation was acknowledged as a methodological limitation that may reduce the representativeness of the qualitative findings. Therefore, the qualitative results were interpreted with caution and supported by triangulation with field notes and quantitative outcomes to enhance credibility. The thematic analysis revealed two overarching themes—advantages and challenges in implementing GBL (Table 5). Students expressed that the GBL method was enjoyable and stimulating, thus fostering a sense of competition and enthusiasm among them. They described it as an innovative learning approach that encouraged active participation and helped them understand anatomy concepts more effectively. For example, one student mentioned that GBL helped them recall errors more easily and motivated them to review the material. These results are consistent with the characteristics of Gen Z learners, who tend to be creative, competitive, and highly responsive to interactive learning environments (23,24).

Students also highlighted that GBL facilitated self-reflection and served as a diagnostic tool for identifying areas that require further study. The interactive nature of Kahoot! provided immediate feedback, thereby enabling students to evaluate their understanding in real time. These perceptions are consistent with the findings of Ismail et al. (25), who emphasised that Kahoot! supports formative assessment, feedback, and reflection among medical students.

However, a few challenges were also reported. The most common issues were unstable internet access and limited time allocation, which occasionally disrupted concentration during sessions. These barriers mirror previous research that emphasises that successful digital learning implementation heavily depends on institutional support and adequate technological infrastructure (26,27).

From a theoretical standpoint, the effectiveness of GBL in this study aligns with the constructivist learning theory, which posits that learners actively build knowledge through experience, interaction, feedback, and reflection (12,13). Padirayon et al. (28) demonstrated that mobile game applications effectively apply constructivist principles by enabling students to construct new knowledgfrom prior experience, as evidenced by the significant improvements between pretest and posttest scores in this study. GBL mirrors this process by immersing learners in dynamic, problem-based environments that stimulate critical thinking and engagement.

Moreover, GBL promotes scaffolding—providing temporary support that enables learners to progress toward independent mastery. As described by Saye and Brush (29) and Chang et al. (30), scaffolding facilitates deeper understanding by gradually reducing instructional support as learners gain competence. Similarly, GBL features progressively more difficult levels, prompting students to apply previously acquired knowledge and develop higher-order thinking skills such as critical analysis, clinical reasoning, problem-solving, and decision-making.

Additionally, GBL enhances motivation and reduces learning anxiety through gamified elements, such as point systems, rankings, and audiovisual feedback. Du et al. (26) and Wang and Tahir (27) noted that these features improve classroom dynamics, stimulate curiosity, and encourage continuous learning. Such reinforcement mechanisms explain the improved knowledge retention observed in the intervention group of this study. Specifically, the feature that displays the highest points at the end of the session indicates their knowledge of the material and enables them to compare their abilities with those of their peers as well as to reflect on their strengths and weaknesses regarding the topic studied. Then, instructors can provide direct feedback and explain the material related to the questions in Kahoot! (25,28).

Therefore, the integration of GBL into anatomy instruction can be viewed as a complementary strategy rather than a replacement for conventional cadaver-based learning. While GBL enhances motivation, engagement, and retention, traditional approaches remain essential for spatial and structural understanding of anatomy that cannot be fully achieved through digital games.

Overall, this study supports the growing body of evidence that GBL is an effective pedagogical tool for improving academic performance, motivation, and engagement among Gen Z medical students. It bridges the gap between modern and traditional learning paradigms and aligns with the constructivist view that meaningful learning occurs when students actively construct knowledge through interactive and reflective experiences.

## CONCLUSION

The findings of this study reveal that GBL is a promising pedagogical innovation for enhancing learning outcomes in contemporary medical education. Specifically, the findings support the strategic integration of GBL into anatomy curricula to enhance Gen Z learners' motivation, engagement, and knowledge retention, thus aligning with constructivist principles which emphasise learner engagement, feedback, and experiential understanding. The students confirmed these findings, stating that this method made learning more enjoyable and increased their motivation by stimulating their competitive spirit.

This study has a few limitations. First, the initial differences in characteristics—such as in baseline GPA and motivation—were not explicitly controlled for. Second, although randomisation was employed, best practice recommends assessing and reporting prognostic baseline variables and applying covariate-adjustment models if a significant imbalance occurs. To address this, future analyses could incorporate analysis of covariance or multiple regression, with GPA and motivation as covariates, to improve precision and reduce potential bias.

Further, the additional considerations that were not explored in this study—such as institutional support (e.g., internet access), sufficient time allocation, and the expertise of teaching staff in managing game-based platforms—should be evaluated in future research. Moreover, future research should include the longitudinal tracking of performance, cross-institutional trials, and analysis of GBL's impact on cognitive retention in disciplines such as physiology and neuroscience. Long-term retention, multicentre replication, and comparison of different GBL platforms across cultural contexts are also important directions for future research.

Overall, GBL represents a promising pedagogical innovation for enhancing learning outcomes in contemporary medical education.

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## ETHICAL APPROVAL

This study received approval from the medical school of Universitas Andalas, Indonesia, prior to the start of the research (Approval no. 64/UN.16.2/KEP-FK/2024).

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