BIOTIK
Jurnal Ilmiah Biologi Teknologi dan Kependidikan
P-ISSN: 2337-9812, E-ISSN: 2549-1768
Vol.13, No.2, 2025. Page193-206

Integrating Gamified Blended Learning in Biology Education: Enhancing Scientific Literacy and Critical Thinking Skills in Higher Education

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Accepted : 24 Sep 2025
Published: 29 Sep 2025

Abstrak: Dalam konteks pendidikan tinggi Indonesia, pendekatan pembelajaran konvensional yang berpusat pada dosen masih dominan, sehingga menghambat keterlibatan aktif mahasiswa dan pengembangan keterampilan berpikir tingkat tinggi, khususnya dalam pembelajaran biologi yang menuntut pemahaman konseptual, kemampuan analitis, dan penerapan ilmiah. Penelitian ini bertujuan untuk menganalisis peningkatan literasi sains dan kemampuan berpikir kritis mahasiswa setelah diterapkannya pembelajaran blended yang digamifikasi pada materi Anatomi Akar. Penelitian ini menggunakan Mixed Methods Research (Metode Campuran) dengan pendekatan desain quasi-eksperimental. Hasil analisis literasi sains menunjukkan nilai t_{hitung} sebesar 9,45, lebih besar dari t_{tabel} 1,54 pada taraf signifikansi 0,05, serta nilai signifikansi 0,00 < 0,05. Selain itu, hasil uji t pada hasil kemampuan berpikir kritis memperkuat temuan tersebut dengan nilai t_{hitung} 7,48 > t_{tabel} 1,34, yang mengindikasikan adanya perbedaan yang sangat signifikan antara rata-rata nilai N-gain mahasiswa pada kelas eksperimen dan kelas kontrol. Dengan demikian, hipotesis alternatif (Ha) diterima, yang berarti model pembelajaran blended learning yang digamifikasi efektif dalam meningkatkan kemampuan berpikir kritis dan literasi sains mahasiswa.

Kata kunci: Pembelajaran Blanded; Gamifikasi; Literasi Sains; Kemampuan Berpikir Kritis.

Abstract: The context of Indonesian higher education, conventional learning approaches centered on lecturers are still dominant, thus inhibiting active student involvement and the development of higher-order thinking skills, especially in biology learning that requires conceptual understanding, analytical skills, and scientific application. This study aims to analyze the improvement of students' scientific literacy and critical thinking skills after the implementation of gamified blended learning on the material of Root Anatomy. This study uses Mixed Methods Research with a quasi-experimental design approach. The results of the scientific literacy analysis show a t-value of 9.45, greater than the t table of 1.54 at a significance level of 0.05, and a significance value of 0.00 <0.05. In addition, the results of the t-test on the results of critical thinking skills strengthen these findings with a t-value of 7.48> t table 1.34, which indicates a very significant difference between the average N-gain values of students in the experimental class and the control class. Thus, the alternative hypothesis (Ha) is

accepted, which means that the gamified blended learning model is effective in improving students' critical thinking skills and scientific literacy.

Keyword: Blended Learning; Gamification; Science Literacy; Critical Thinking Skills.

1. Introduction

Entering the 21st century, the global education system faces new challenges that demand a paradigm shift in learning. The rapid development of information technology, the complexity of global challenges such as climate change, pandemics, and digital disruption required the education system, especially higher education, to not only focus on knowledge transfer, but also on developing the skills of this century. Among the most crucial are scientific literacy and critical thinking skills [1].Today's students are classified as a digital native generation, which has different learning characteristics from previous generations. They tend to get bored more quickly with passive learning methods and are more responsive to interactive, collaborative, and digital learning [2]. Unfortunately, in the context of higher education in Indonesia, there are still many institutions that apply a conventional teacher-centered learning approach, which results in minimal active involvement of students in the learning process and low development of high-level thinking skills [3]. Especially in the field of science such as biology, this approach is considered less relevant because learning biology should require conceptual understanding, analytical skills, and scientific application in real-life contexts.

Biology education has a very strategic role in developing students' scientific literacy. Scientific literacy is not only related to understanding scientific concepts and processes, but also the ability to critically evaluate scientific information, make decisions based on evidence, and understand the impact of science and technology on society and the environment [4]. However, the results of several surveys show that the level of scientific literacy of Indonesian students is still below the average of other countries [5]. The most students still have difficulty linking biological concepts to contextual problems, and show low critical thinking skills in interpreting scientific data [6].

A lecturer who acts as a driving force must be able to implement innovative and creative learning strategies, using various media and adequate learning resources [7]. In facing this condition, the blended learning approach has begun to be widely viewed as a strategic alternative. Blended learning is a learning model that combines face-to-face learning and online learning with the aim of optimizing the learning process [8]. This approach allows for personalization of learning, flexibility of time and place, and integration of technology that suits the learning styles of today's students. In the post-COVID-19 pandemic era, blended learning is no longer an alternative choice, but rather an urgent need in the world of global higher education [9]. A study conducted stated that blended learning can significantly increase learning motivation, digital skills, and conceptual understanding of biology students compared to conventional learning models [10].

However, the challenge in implementing blended learning is how to maintain active student engagement during the learning process. One promising innovative approach to address this is the application of gamification in learning. Gamification is the application of game elements such as points, levels, leaderboards, challenges, and rewards in a non-game context to increase student engagement, motivation, and learning outcomes [11]. In biology learning which is often considered difficult and boring because of abstract and complex content, gamification is able to present a fun, challenging, and meaningful learning atmosphere [12].

The integration of gamification into blended learning (blended-gamified learning) is believed to produce positive synergy in the learning process. This model allows students to learn flexibly while remaining motivated and active because of the embedded game elements. Integration of gamification in blended learning can increase learning persistence, academic achievement, and student learning satisfaction in various fields, including science [13]. In the field of biology education, gamification has been shown to encourage students to think analytically, conduct independent exploration, and solve problem-based tasks creatively [14].

Furthermore, critical thinking skills are an important element that needs to be developed through biology learning. Critical thinking includes the ability to analyze, evaluate, and conclude information logically and objectively [15]. This skill is very relevant to the goals of higher education because it prepares students to become scientists, professionals, and citizens who are able to make intelligent decisions in real life. A recent study showed that a blended-gamified learning-based learning approach can improve students' critical thinking skills through strategies such as problem-based learning, interactive discussions, and independent reflection packaged in a game format [16].

Thus, it can be concluded that the integration of blended learning and gamification in biology education is a promising strategy in improving scientific literacy and critical thinking skills of students in higher education. This research is important to develop innovative learning models that are relevant to the demands of the digital era and support the development of 21st-century competencies of Indonesian students. It is hoped that the results of this study can contribute to the development of curriculum, learning strategies, and higher education policies in the field of science, especially biology. This study aims to analyze the increase in scientific literacy and critical thinking skills of students after the implementation of blended learning that is gamified in the material of Root Anatomy. The results are analyzed based on the main indicators of each variable.

2. Research Method

This study uses Mixed Methods Research with a quasi-experimental design approach to evaluate the effectiveness of the implementation of Blended Learning based on Gamification and Project-Based Learning in improving scientific literacy, critical thinking skills [17]. This approach combines quantitative and qualitative research to obtain more comprehensive results. The research design applied is Non-Equivalent Control Group Design, which involves two groups: an experimental group that receives learning with the Blended Learning model based on Gamification and Project-Based Learning, while the control group follows learning with Project Based Learning only [18].

a. Population and Research Sample

The population in this study included students of Biology Education at Muhammadiyah University of Aceh. The sample in this study were students taking the Plant Anatomy course. The sample determination was carried out using a purposive sampling technique, with the criteria being students taking the course, willing to follow all levels of research, and having access to digital devices and the internet to support Blended Learning. The samples taken consisted of at least two classes, one class functioning as an experimental group and one class as a control group [19] with a total of around 60 students.

b. Data collection technique

This study applies quantitative descriptive method as its main approach. Data collection techniques are carried out by giving written tests that aim to measure the level of scientific literacy and critical thinking skills in Biology students. The research instrument used is in the form of test questions that have been systematically arranged to evaluate the two variables.

c. Data analysis techniques

The data obtained were then analyzed using quantitative descriptive analysis techniques, which include three main stages, namely data collection, data processing, and interpretation of the results of quantitative data analysis.

d. Research Procedure

This research consists of three main stages, namely the preparation stage, the implementation stage, and the analysis and reporting stage.

1. Preparation Stage

   In the preparation stage, the preparation of research instruments was carried out which included pretest-posttest questions for each scientific literacy and critical thinking skills, as well as the development of learning modules to adjust the use of Blended Learning based on gamification and

Project-Based Learning (PjBL) and create gamification. In addition, training was carried out for lecturers who would teach using this new approach and validation of research instruments by experts.

2. Implementation Stage

The implementation of the research began with the provision of a pretest and introduction to the learning model in the first week, followed by the implementation of learning for the next three weeks. In the sixth and seventh weeks, a posttest was conducted. The stages of Blended Learning with gamification and Project-based learning are as follows:

a. Pre-lecture (via LMS): Lecturers upload learning materials, videos, and supporting images. Lecturers and students hold forum discussions, students discuss questions asked by the lecturer. Students are asked to prepare samples of plant parts according to the topic of discussion (Roots, Stems, and Leaves) to be brought to face-to-face meetings.

b. During lectures (face-to-face): lecturers conduct apperception, material exploration, observation and documentation as part of the project, students complete challenges (gamification), the results are uploaded to the LMS, and get peer review from each other. Finally, lecturers and students will reflect and close the lecture.

3. Final Stage

The final stage includes data analysis and interpretation of results to answer the problem formulation, as well as compiling the article.

3. Results and Discussion

a. Initial Research Data

The data used to measure scientific literacy were obtained from students' initial knowledge. Before implementing the blended learning model, a pretest was conducted to determine whether the initial abilities of students in both classes were equivalent. The results of the analysis showed that there was no significant difference in the abilities and initial knowledge between the experimental class and the control class.

Tabel 1. Results of the Pretest Average Difference Test

Average	Class		Normality		Homogeneity	Significance
	Exp.	Cont.	Exp.	Cont.		
Pretest Learning Results	58	54,5	Normal X^2_{Count} (6,91)< $X^2_{tab.}$ (12,07)	Normal X^2_{Count} (5,14)< $X^2_{tab.}$ (12,07)	Homogen F_{Count} (0,81) < $F_{Tab.}$ (1,75), α 0,05	Not significant t_{Count} (1,45) < $t_{tab.}$ (1,745) α 0,05

Based on the results of the analysis, both groups of data have a normal distribution and are homogeneous, so it can be concluded that students in the experimental class and the control class have equal initial abilities and knowledge in terms of learning outcomes. Furthermore, the two classes were given different treatments: the experimental class used a blended learning model, while the control class used a project-based learning (PjBL) method.

b. Science Literacy Results

The results of the analysis of scientific literacy data were obtained from tests created based on scientific literacy indicators referring to the framework including: Explaining scientific phenomena, Designing and evaluating scientific investigations, Interpreting scientific data and evidence. The results of the achievement of the Scientific Literacy Indicators for the control class and the experimental class are presented in Table 2 and Table 3.

Table 2. Average Achievement of Science Literacy Indicators in Control Class

Science Literacy Indicators	Pretest Score (%)	Posttest Score (%)
Explaining scientific phenomena	54,8	68,7
Designing & evaluating scientific investigations	57,1	66,3
	51,5	67,5
Average	**54,5**	**67,5**

Tabel 3. Average Achievement of Science Literacy Indicators in Experimental Class

Science Literacy Indicators	Pretest Score (%)	Posttest Score (%)
Explaining scientific phenomena	55,1	80,3
Designing & evaluating scientific investigations	60,2	84,6
	58,7	83,5
Average	**58,0**	**82,8**

The highest increase interpretation is seen in the indicator of designing and evaluating scientific investigations, which shows that students are more trained in systematic thinking through gamification activities based on virtual experiments and problem-based case studies. Based on the results of the study, it can be seen that the comparison between the scores obtained on the Science Literacy Test at the Pretest and Posttest is significantly different. This has been described in Table 4.

Table 4. Results of the N-gain Average Difference Test for Science Literacy

Average	Class		Normality		Homogeneity	Significance
	Exp.	Cont.	Exp.	Cont.		
N-gain Learning Outcomes	82,8	67,8	Normal X^2_{Count} (6,91)< $X^2_{tab.}$ (12,07)	Normal X^2_{Count} (5,14)< $X^2_{tab.}$ (12,07)	Homogen F_{Count} (2,31) < $F_{Tab.}$ (1,85), α 0,05	Not Significant t_{Count} (9,45) < $t_{tab.}$ (1,54) α 0,05

Based on the results of the analysis in the table, the results of the statistical test using the t-test showed that the t-value was 9.45, while the t-table value at the significance level (α = 0.05) was 1.54. These results indicate that there is a very significant difference between the average N-gain value of students in the experimental class and the control class. Thus, the research hypothesis is accepted, namely that there is a significant difference in science literacy results between students who take part in gamified blended learning in the experimental class and students who receive learning using the Pjbl learning model in the control class.

This is in line with several other studies showing that the application of the blended learning model can significantly improve students' scientific literacy. Through meta-analysis found that blended learning is effective in

improving scientific literacy at the high school/vocational high school level [20]. The STEM-based blended learning approach can improve students' scientific literacy skills in biology learning during the pandemic [21]. Similar research also showed that the combination of blended learning and the STEM approach resulted in a high average scientific literacy score in students [22]. In addition, strengthened these findings by showing that the Blended Project Based Learning (Blended-PjBL) model accompanied by students' initial understanding was able to strengthen students' conceptual understanding and scientific literacy [23]. Overall, blended learning has been shown to improve scientific literacy through the integration of technology, problem-based approaches, and active involvement of students in the learning process.

c. Critical Thinking Skills Results

Critical thinking skills are analyzed based on several indicators consisting of: Interpretation, Analysis, Evaluation, Inference, Explanation and Self-regulation [15].

Table 5. Results of Achievement of Each Aspect of Critical Thinking Skills in the Control Class

Critical Thinking Indicators	Achievement (%)	
	Pretest	Posttest
Interpretation	52,3	71,0
Analysis	61,1	70,9
Evaluation	60,4	77,1
Inference	57,7	70,3
Explanation	62,1	79,2
Self-reflection	58,2	79,9
Average	**58,6**	**74,7**

From Table 5, it can be seen that the results of the control class' critical thinking skills during the pretest and posttest increased, although not much different. The average pretest score was 58.6 while the posttest score was 74.7, only a difference of 16.1%. This is because the control class also applies the PjBl learning model. This result is in line with previous research which stated that the use of project-based learning models has an effect on the critical thinking

skills of class X students at MAN Model Banda Aceh. The average value obtained by students was 88, while the KKM for biology subjects was 80. The results of statistical calculations using the t-test obtained t_{count} = 13.62, while t_{table} = 2.04, if $t_{count} > t_{table}$ then Ha is accepted, while if $t_{count} < t_{table}$, then Ho is accepted [24].

Table 6. Results of Achievement of Each Aspect of Critical Thinking Ability in the Experimental Class

Critical Thinking Indicators	Achievement (%)	
	Pretest	Posttest
Interpretation	62,3	84,0
Analysis	60,1	82,7
Evaluation	59,4	85,3
Inference	58,9	83,0
Explanation	61,7	81,2
Self-reflection	55,2	78,9
Average	**59,6**	**82,5**

The average critical thinking ability of students in the experimental class was 82.5, higher than the control class which only reached 74.7. The evaluation and inference indicators experienced the most significant increase. This shows that students are helped by learning strategies that involve decision making, reflection on friends' solutions, and scenario-based problem solving using the blended learning model on the Root Anatomy topic.

Table 7. Results of the N-gain Mean Difference Test of Critical Thinking Ability

Rerata	Class		Normality		Homogeneity	Significance
	Exp.	Cont.	Exp.	Cont.		
N-gain Learning Outcome	82,5	74,7	Normal X^2_{Count} (5,91)< $X^2_{tab.}$ (13,09)	Normal X^2_{Count} (6,14)< $X^2_{tab.}$ (13,09)	Homogen F_{Count} (2,31) < $F_{Tab.}$ (1,85), α 0,05	Not significant t_{Count} (7,48) < $t_{tab.}$ (1,34) α 0,05

Based on Table 7. The difference in the average of the two classes, the analysis of the results of the independent sample test shows a significance value of 0.00 <0.05 and the calculated t value> t table or 7.48> 1.34, so Ha is accepted and Ho is rejected, which means that the gamified blended learning model can significantly improve students' critical thinking skills in the Root Anatomy material.

The results of this study are in accordance with research conducted which found that blended learning has a positive correlation with students' critical thinking skills, although it is relatively weak, it still shows a positive tendency [25]. Stated that students' perceptions of a blended learning environment that is designed pedagogically, socially, and technically can improve various aspects of critical thinking [26]. research on biology students showed that blended learning can significantly improve critical thinking skills and learning motivation [27].

Similar results were also found who proved that elementary school students who studied using a blended learning approach showed increased critical thinking skills and better science learning outcomes compared to conventional methods [28]. Through a literature study also concluded that the blended learning model is effective in improving critical thinking skills and science processes in physics learning [29]. Overall, these studies confirm that blended learning is a relevant and effective learning strategy in encouraging the development of critical thinking skills in various learning contexts.

4. Conclusion

This study shows that the implementation of the gamified blended learning model significantly improves students' scientific literacy and critical thinking skills in the Root Anatomy material. This is evidenced by the results of the t-test on the results of the scientific literacy analysis which shows a t_{value} of 9.45, greater than the t_{table} of 1.54 at a significance level of 0.05, and a significance value of 0.00 < 0.05. In addition, the results of the t_{test} on the results of critical thinking skills strengthen these findings with a t_{value} of 7.48 > t_{table} 1.34, which indicates a very significant difference between the average N-gain values of students in the experimental class and the control class. Thus, the alternative hypothesis (Ha) is accepted, which means that the gamified blended learning model is effective in improving students' critical thinking skills and scientific literacy.

5. Acknowledgments (*Ignore if unnecessary*)

The author would like to express his deepest gratitude to the Directorate of Research, Technology, and Community Service (DRTPM), Ministry of Higher Education, Science and Technology of the Republic of Indonesia (BIMA Kemdikbudristek) for the support and funding that has been provided in the implementation of this research through a research grant program that is very useful in the development of science. Gratitude is also expressed to the Institute for Research, Development, Community Service, and Scientific Publication (LP4M) of the University of Muhammadiyah Aceh (UNMUHA) for administrative support and facilitation during the implementation of this research activity. Not to forget, the author expresses his sincere appreciation to all staff and employees of the Faculty of Islamic Studies (FAI) of the University of Muhammadiyah Aceh, who have provided technical assistance, moral support, and very meaningful cooperation in every stage of the implementation of this research.

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