https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/69035
https://doi.org/10.24114/njtxny29 - (Vol 18, No 1 – 2026)
available at http://jurnal.unimed.ac.id/2012/index.php/geo
e-issn (2549-7057) & p-issn (2085-8167)

Accelerating Sustainability Competencies in the Younger Generation through the Problem-Based Gamification Learning Model

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ARTICLE INFO
Article History:
Received: September 09, 2025
Revision: February 15, 2026
Accepted: February 18, 2026

Keywords:
Problem-Based Learning;
Gamification Learning;
Inovation Learning Model;
Sustainability Competencies

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ABSTRACT
Higher education faces the challenge of shaping a young generation that cares about the environment. However, in reality, young people still face difficulties in developing sustainable skills. Problem-Based Game-Based Learning (PBGL) is learning innovation for shaping sustainable competencies. The aims of this study were to determine students' sustainable competencies, determine the effect of length of study on sustainable competencies, and analyse the effect of the PBGL model on sustainable competencies. To analyse the influence of PBGL, a pretest-posttest quasi-experimental design with a control group was used. Meanwhile, to determine the differences in sustainability competencies based on length of study, the Mann-Whitney U test was used. The instrument used was modified from the sustainability competency instrument to suit the characteristics of the research subjects. The results show that sustainability competencies before treatment were at a moderate level. After treatment, the experimental group showed an increase in holistic thinking to 90.5%, followed by an increase in conflict resolution to 95.37%. The experimental group showed a significant increase ($t=13.462$, $p<0.001$) with an increase in competence exceeding that of the control group. When viewed from the difference in length of study, there is a significant difference between fifth-semester and seventh-semester students. Seventh-semester students demonstrate higher competence than fifth-semester students ($p<0.05$). The difference in average shows a 10% difference. This indicates that academic maturity affects the effectiveness of PBGL and sustainability competence. The results show that the PBGL model is able to accelerate the development of sustainability competencies. This study has important theoretical and practical implications for the improvement of sustainable environmental curricula and higher education learning.

INTRODUCTION

Environmental degradation has become a global issue alongside rapid technological development. Environmental degradation causes numerous environmental problems, one of which is global warming (Suki et al., 2022; Zaizay et al., 2024). Global warming has become an interesting research focus that has been studied by several researchers around the world, especially in the field of education. Many researchers have integrated learning to raise awareness of global warming (Hurlimann et al., 2024; Keller et al., 2024; Kolenatý et al., 2022; Tolppanen et al., 2022).

Amidst the climate crisis and environmental degradation, higher education has a responsibility to strengthen environmental awareness among the younger generation. Environmental

awareness is the awareness of the attitudes and actions of individuals or groups that can be seen from their knowledge and attitudes in taking concrete actions to protect environmental sustainability (Rahmawati et al., 2020; Shendell et al., 2023). Universities have made many efforts, both in terms of regulations and curriculum (Hurlimann et al., 2024; Puertas et al., 2023). However, in reality, there are still obstacles.

One part of the effort to shape environmental awareness is to increase environmental awareness skills. There is a challenge in that there is still a lack of critical, systematic, and collaborative thinking skills, especially in dealing with environmental issues (Ridhwan et al., 2020; Sari et al., 2023). Universities have made many efforts to improve environmental sustainability (Vallée, 2023). However, sustainability competencies are still low. This can be seen from the limitations of students in identifying the interrelationships between environmental issues and formulating problem-solving strategies (Hyytinen et al., 2023; Redman et al., 2021).

Curricula in universities and schools still lack content on sustainable education. This results in low student awareness of environmental issues. Research Gayatri et al., (2023) in six schools in Indonesia found that prospective teachers' knowledge of sustainable education was very limited. Furthermore, in practice, environmentally friendly initiatives in higher education institutions focus on increasing knowledge, but students are not yet able to integrate this into their daily actions (Djirong et al., 2024). The main problem with sustainability education in higher education is the lack of inclusion of sustainability-related content in the curriculum, lecturer quality, and regulations.

One learning model that offers improved problem-solving skills is the problem-based learning (PBL) model. Various studies have proven that the PBL model is effective in improving environmental problem-solving skills (Amin et al., 2020; Purnomo et al., 2023; Sumarmi et al., 2020). PBL has been proven effective in addressing environmental challenges, but its impact on improving sustainability competencies still needs to be explored (Cong & Ironsi, 2025; D'Escoffier et al., 2024; Nguyen et al., 2024). This shows that the development of PBL is relevant to sustainability competencies, but it still needs to be developed to increase the effectiveness of PBL

Integrating PBL with gamification is a solution that can improve students' sustainability skills. Learning through games allows students to learn independently (Sari et al., 2025). Furthermore, gamification has been proven to increase motivation and active involvement in learning activities (Kramar & Knez, 2025). Gamification includes elements of points, rewards, and exploration of problems and learning progress levels, providing students with more specific input in the process of providing solutions to problems.

PBGL was created as an innovative model that combines PBL and gamification elements in learning. PBGL not only increases motivation and engagement in learning activities but also develops soft skills such as collaboration, creativity, and decision-making skills (Čubela et al., 2023). These abilities are important for the development of sustainable competencies (Costa & Cipolla, 2025; Farao et al., 2023). Through in-depth investigative learning and challenging levels, learning becomes challenging, increasing students' enthusiasm for problem solving.

However, very little empirical research has been conducted on the integration of PBL and gamification. This is confirmed by research Lim et al., (2025) and Mabalay (2025), which shows that the explicit integration of gamification in sustainability learning still has many gaps. This indicates that PBL learning integrated with gamification needs more attention.

The PBGL learning model has great potential to improve the quality of learning. The results of research Satapanasatien et al. (2021) show that the integration of learning with gamification supports students' ability to reflect on learning outcomes and assists in decision-making. Furthermore, Palaniappan

& Noor (2022) found that students who participated in learning using the gamification learning model showed higher learning independence compared to conventional learning. This confirms that PBGL learning is strategic in supporting the improvement of learning quality.

Although previous studies have shown the effectiveness of PBL and gamification models in increasing learning motivation and problem-solving skills, there has been no research that highlights the integration of PBL and gamification models through the latest PBGL model innovation and measures its effect on sustainability competencies, both practically and conceptually. Previous research has positioned gamification as a tool used to increase learning motivation and problem-solving (Mabalay, 2025). Most studies have focused only on thinking skills, but there is no literature specifically testing the influence of gamification and PBL on sustainability competencies through indicators of holistic thinking and conflict resolution. Furthermore, no other research has explored the PBGL model through a quasi-experimental research design with progressive level-based challenges and strategies for students. This research is also unique in its research design, where the effectiveness of the PBGL model is tested using a pretest-posttest quasi-experimental design, and adds an in-depth analysis of its influence based on differences in the length of study of students.

This study has the main objective of testing the effectiveness of the PBGL model in improving sustainability competencies. However, there are several questions answered in this study, namely: a) What are the students' initial sustainability competencies? b) How do sustainability competencies differ when viewed from the length of study/lectures? c) How does PBGL affect the improvement of students' sustainability competencies?

RESEARCH METHODS

Research design

This study has the main objective of examining the effect of problem-based gamification learning models (PBGL) on accelerating students' sustainability competencies. A quasi-experimental design using a pretest-posttest control group was employed. There were two treatment groups. In the experimental group, learning was used with PBGL, while in the control group, we applied conventional learning methods with lectures and group discussions. Table 1 presents the research design.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O1	X	O2
Control	O3	-	O4

(Source: Research Results, 2025)

Description:

O1 : Pre-test of the experimental group
O2 : Post-test of the experimental group
X1 : PBGL learning
O3 : Pre-test of the control group
O4 : Post-test of the control group

The learning programme was designed to last four weeks, with the theme Anticipating the Urban Heat Island Phenomenon in Aceh Province' for two treatment groups. Table 2 presents the learning steps for the experimental group (PBGL model) and the control group (lectures and discussions). Before implementing the learning programme, an initial test was conducted on the students. Then, after the learning programme was implemented, a final test was conducted to determine the development of sustainability competencies.

Table 2. Syntax of learning in the experimental and control groups

Group	Learning Trethment	Syntax	Activities
Experiment	Problem based gamification learning	Problem orientation and mission	The lecturer introduces the topic and presents contextual problems related to urban sustainability as the 'main mission' that students must complete
		Team organisation	The lecturer divides the students into six groups.
			The lecturer explains the learning objectives and the point system
		Initial investigation and information gathering	Students identify initial data, formulate hypotheses, and develop strategies.
			The lecturer gives students the opportunity to develop strategies to be used to complete the simulation game mission.
		In-depth investigation and level challenges	Students try to build a sustainable city design, ecological and economic decisions
		Solution development and presentation	Students process the results of data observations during the simulation using games and other relevant data to create real solutions
		Evaluation and reflection	Students present their solutions
			Lecturers and students jointly evaluate the process and results of solving environmental problems
			Students in other groups listen and respond to the results of the group presentations
		Reward and level up	Students and teams earn checkpoints for the next lesson
Control	Conventional Learning	Introduction	Lecturers convey learning objectives
		Presentation of material	Lecturers explain material using PowerPoint
		Guided question and answer	Lecturers ask questions to test students' understanding
		Group discussion	Students discuss in groups
		Presentation of discussion results	Students present the results of their group discussions
		Reinforcement of material	Lecturer delivers a summary and conclusion
		Closing	Lecturer conducts a brief evaluation to measure understanding

(Source: Research Results, 2025)

Implementation of the PBGL Model

The PBGL model was implemented over a period of 4 weeks. The model was completed in 8 sessions, each consisting of 50 minutes. The PBGL model steps were carried out gradually through problem-solving activities related to sustainability competencies and integrated into gamification. We used an Eco Game simulation game with scoring based on a rubric determined by the researchers.

In the first week, problem, mission orientation, and team organization were carried out. Lecturers introduced contextual topics taken from articles and environmental data. Students were then asked to complete sustainability missions and design mitigation strategies by developing a balance between ecological, social, and economic dimensions through eco games. Students were then divided into small groups (4 students per group). The lecturer explained the learning objectives, sustainability competency indicators, and gamification mechanisms in learning. After conveying the objectives, the lecturer then directed students to identify and formulate hypotheses. Groups received 10 points for their ability to identify sustainability dimensions and 5 points for connecting the interrelationships between dimensions.

The second week of learning consisted of an initial investigation and information-gathering stage. Students conducted investigations and collected data from the game and other sources for 40 minutes, then for the next 30 minutes, students developed simulation strategies and continued by submitting ideas to address urban heat conditions. Points are awarded based on the criteria of the proposed strategy (15 points), the integration of the strategy with sustainability (10 points), and the completeness of data for accurate evidence (5 points).

In the third week, in-depth investigations and level challenges were conducted. Students' activities involved building a sustainable city through a game. Students began implementing the sustainable city design carried out in the second week. The challenge that students had to prepare for was to harmonize ecological, economic, and social aspects. Students who were able to complete the sustainable city design in 100 minutes received 20 points. Students also received 15 points for mapping and 10 points for long-term sustainability planning. Students were required to obtain a score of 70 to continue the activities in the fourth week. Student groups that did not meet the requirements could repeat the activity independently outside of class.

In the fourth week, students begin to develop solutions, evaluate, and reflect. In the first 40 minutes, students are asked to complete a sustainable city design, followed by a presentation of a strategic plan for sustainable city development. Next, the lecturer invites students to provide feedback and reflections. Students receive 25 points for integrated solutions, 15 points for presentations, and 10 points for reflection scores. The PBGL model then concludes with the ranking of student groups by applying a point system, which is then categorized into three categories: bronze (70–89 points), silver (90–109 points), and gold (>110 points). Points are obtained based on the combination of points in each session. A summary can be seen in Table 3.

Table 3. Integration of PBGL, Competency, and Assessment

Week	Syntax and Learning Activities	Competencies	Assessment
1	**Problem Orientation and Mission –** students analyze contextual problems	Identify environmental issues (HT1)	Group- rubric for problem analysis
2	**Problem Orientation and Mission –** Students rank the urgency of problems	Ability to prioritise perspectives (HT2)	Group-rubric environmental issue priorities

3	**Team organisation** – students map potential conflicts for building a sustainable city	identify interrelated sustainability conflicts (CR1)	Group-conflict mapping rubric
4	**Initial Investigation and Information Gathering** – Students provide preliminary problem-solving designs through group discussion	Critical reflection of sustainability values (HT3) Communicate ideas (HT4)	Group – alanysis rubric Individual-communication skills rubric
5	**In-Depth Investigation and Level Challenges** – Students simulate development through games, students choose the best scenario and integrate the three elements of sustainable development	Identify sustainability conflicts (CR1) Prioritise feasible solutions (CR2) Develop realistic strategies (CR3)	Group- rubric for integrating aspects of sustainable development Group – simulation decision rubric Group – simulation ability analysis rubric
6	**Solution Development and Presentation** – Students present sustainable city designs	Communicate ideas (HT4) Develop realistic strategies (CR3)	Group – presentation rubric
7	**Evaluation and Reflection** – Students reflect and explain the rational reasons for their strategy selection	Critical reflection of sustainability values (HT3) Develop realistic strategies (CR3)	Individual – reflection ability rubric Individual – for scoring the ability to give rational reasons
8	**Reward and Level Up** – Students receive feedback and learning progress based on cumulative scores		

(Source: Research Results, 2025)

Assessment in the PBGL model uses group and individual assessment. We use formative assessment by assessing sustainable urban design, problem-solving, and presentation skills. Furthermore, individual assessment is carried out through formative and summative assessments. In formative assessment, we assess individual participation and individual rubric assessment related to HT and CR indicators, while summative assessment is carried out by assessing reflection sheets.

Participants

This study involved geography students from Universitas Samudra in their fifth and seventh semesters of the 2025/2026 academic year who were taking courses in Urban Geography and Rural Community Development. Students were selected as participants because they had passed the environmental geography course. Students who had taken the environmental geography course were assumed to know the environment. Furthermore, students were selected as participants because

campus learning takes a long time, so PBGL learning can be applied more flexibly. Both treatment groups had the same results, with the final result for the environmental geography course having an average score of 70. Table 4 presents the distribution of research participants.

Table 4. Distribution of research participants

Group	Semester	Number
Experiment	5	26
	7	23
Control	5	28
	7	21

(Source: Research Results, 2025)

The selection of participants was made based on various considerations. Fifth- and seventh-semester students have completed basic courses and already have environmental knowledge and systemic thinking skills based on their experience in previous courses. Seventh-semester students, in particular, have taken advanced courses that reflect their academic maturity. This is supported by research Scoulas et al., (2025), which states that final-year students have a higher level of learning maturity and management skills. This selection is suitable for observing the effect of the model intervention on the length of the study. Furthermore, the involvement of fifth- and seventh-semester students is more feasible than that of students at other academic levels because they have the appropriate schedule for learning using the PBGL model, which lasts for four weeks, as they have relevant courses and are not taking thesis courses that require students to work full-time outside the classroom.

Instrument and data collection

The study used a sustainability competencies measurement instrument modified from (Doucette et al., 2013). The instrument consisted of an assessment rubric and cases taken from national news articles. Modifications were made to adjust the language and context to suit university students. The aim was to make the instrument more contextual in assessing sustainability competencies. The case presented issues related to global warming with an article entitled "*Hari ini Banda Aceh Jadi Daerah Terpanas di Indonesia, Suhu Mencapai 37,2 derajat, BMKG: Ekstream* (Today Banda Aceh Becomes the Hottest Region in Indonesia, Temperature Reaches 37.2 Degrees, BMKG: Extreme)" accessible at the link https://aceh.tribunnews.com/2025/07/01/hari-ini-banda-aceh-jadi-daerah-terpanas-di-indonesia-suhu-capai-372-derajat-bmkg-ekstream. Contextual case studies were selected so that students could understand and be sensitive to environmental issues in their region (Abu-Rasheed et al., 2023; Sari, Ridhwan, Sahudra, Urfan, et al., 2025). Contextual issues are interesting and motivate students to solve problems (Arrhenius et al., 2022; Sari, Febri, et al., 2025).

Students were required to provide solutions consisting of main solutions and alternative solutions. Furthermore, the evaluation instrument was developed with the assistance of two experts in the fields of learning and the environment. Researchers and experts collaborated in developing the answer key. The modified rubric contains scores from 1 to 5, where 0 means that the student has not been able to solve the problem and 5 means that the student has been able to comprehensively solve the environmental problem, provide alternative solutions, and give reasons for choosing the main solution.

The sustainability competency measurement tool was then tested for validity and reliability among students who had taken environmental geography courses. A total of 35 students participated in testing the validity and reliability of the questions. The validity test results showed

that the instrument was valid with a validity value of (0.818–0.940) > r-table (0.334) and a Cronbach's alpha value of (0.928), indicating that the questions had a high level of reliability. The results of the rubric containing indicators and sub-indicators are shown in Table 5.

Table 5. Sustainability Competencies Indicators

No	Indicator	Sub-indicator	Questions
1	Holistic Thinking (HT)	Ability to identify environmental issues (HT1) Ability to prioritise perspectives (HT2) Ability to identify and critically reflect on sustainability values (HT3) Ability to communicate ideas (HT4)	1. Explain the issues presented in the article. (HT1) 2. Identify all aspects of the social, environmental, and economic challenges of the case. (HT1) 3. Identify priority issues presented in the article that take into account the principles of sustainability. (HT2) 4. Identify in depth and critically reflect on the values underlying the case. (HT3) 5. Analyse in depth why the issue occurred. (HT4)
2	Conflict Resolution (CR)	Ability to identify interrelated sustainability conflicts (CR1) Ability to identify possible priority solutions (CR2) Ability to formulate realistic strategies (CR3)	6. Link all interrelated sustainability priority conflicts in the case (environmental, social, and economic (CR1) 7. Analyse possible solutions that are in line with the values used for environmental sustainability. (CR2) 8. Develop several strategies to implement each solution to prioritise sustainability (CR3) 9. Provide recommended solutions that reflect consideration and integration of environmental, social, and economic aspects. (CR3) 10. Provide reasons for the recommended solutions. (CR3)

(Source: Research Results, 2025)

Data analysis

The initial distribution data of sustainability competencies was analysed using percentages. Subsequently, to determine the effect of the PBGL model, the data were analysed using an independent t-test. To meet the testing requirements, the data were first analysed for normality and homogeneity. The data were analysed using a significance level of 5%. The hypothesis in this study was H0: if the sustainability competencies before and after the implementation of PBGL were the same, and the hypothesis was accepted (H1) if there was a difference in sustainability competencies before and after the implementation of PBGL. If the significance value was <0.05, the research hypothesis (H1) was rejected. SPSS 25 was used to assist in analysing the research data. The research design is shown in detail in Figure 1 below.

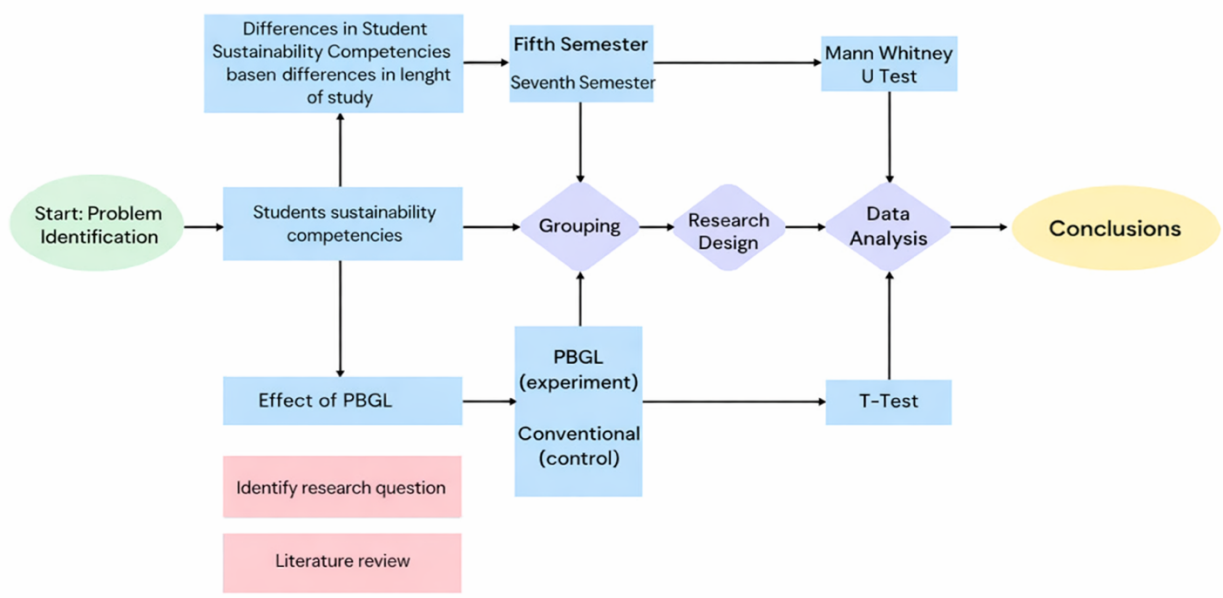

Figure 1. Research Design (Source: Research Results, 2025).

Research Outline

This research has a structured and systematic research sequence. First, we developed a conceptual PBGL model for sustainability competencies. The development of this PBGL model was based on several stages, namely a needs study, designing a conceptual model by seeking a theoretical basis for the development and integration of the PBL and gamification models, and integrating them with sustainability competency indicators. Next, the model was developed and tested for implementation to see the practicality of the game. After the PBGL model was developed, we then developed and validated the sustainability competency instrument through expert assessment and tested the validity and reliability of the instrument on 35 students. After the conceptual model and assessment instruments were developed, we continued with the research design using a pretest-posttest quasi-experiment. The experimental class used the PBGL model, and the control class used the conventional learning model. Before the learning intervention, a pretest was conducted using the sustainability competency instruments on the two groups. Next, a 4-week learning intervention was conducted using the PBGL learning model (experimental group) and the conventional model (control group). After the intervention, a post-test was conducted on the two groups. Next, a quantitative analysis was conducted in the form of calculating normality and homogeneity as requirements for the T-test, independent sample T-test analysis, and comparison based on the length of the study. The length of study data was taken from student demographic data.

RESULTS AND DISCUSSION

Initial Sustainability Competencies

Sustainability competencies are one of the factors that support pro-environmental behaviour. Sustainability competencies are the ability to understand, analyse, and address holistic challenges (Sattich et al., 2024). Sustainability competencies require transformative thinking in addressing environmental issues (Sari et al., 2025).

Sustainability competencies differ from basic cognitive thinking. These competencies require the ability to connect aspects of a problem, such as causes and effects, from various perspectives, including environmental, social, and economic (Redman & Wiek, 2021).

Sustainability competencies require systems thinking. Students do not just look at a problem and think of a solution, but connect it to a broader view with an

interdisciplinary perspective (Karayol & Umdu Topsakal, 2025). In sustainability competencies, students must also have the ability to logically analyse a problem, address the emotional aspects of the problem, and choose from a variety of solutions. Therefore, problem-based learning that focuses on solving contextual problems is needed. Initial abilities before treatment can be seen in Figure 2.

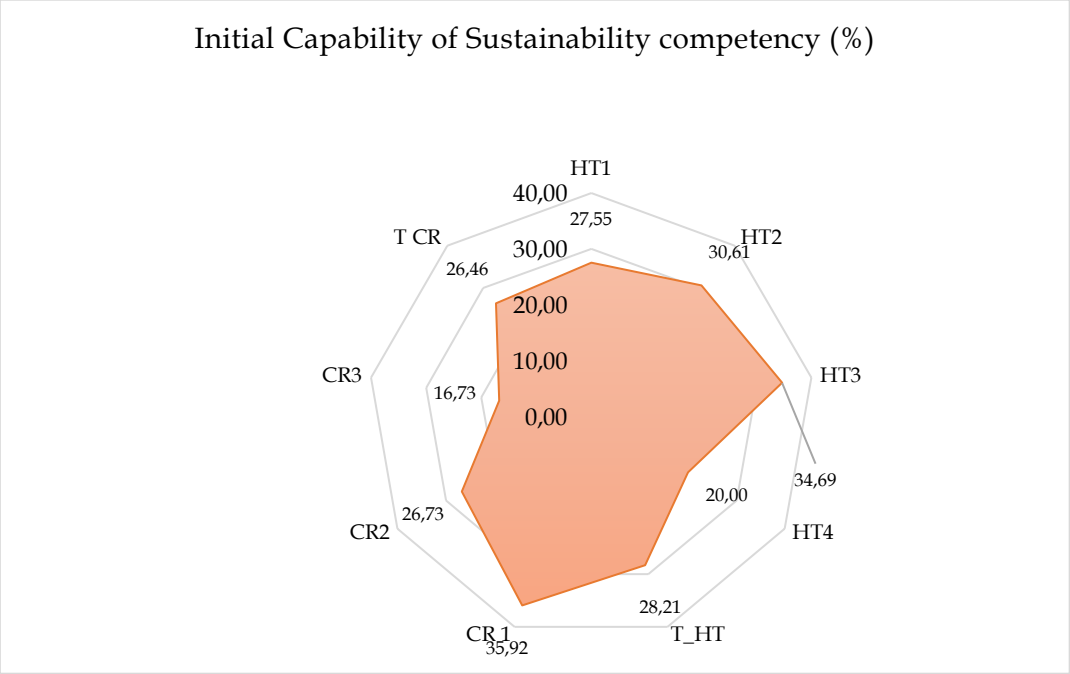

Figure 2. Percentage of students' initial sustainability competency (Source: Research Results, 2025).

The graph shows that students' initial sustainable competence scores were unevenly distributed. The highest initial score was on CR 1 (35.92%), indicating that students have relatively better abilities in identifying problems. However, the lowest scores were seen on CR3 and HT 4 (16.73% and 20.00%), indicating that their competencies are still lacking or limited in further decision-making. Conflict resolution skills reflect students' weaknesses in analyzing and integrating sustainability competencies. This means that students already have awareness but are not yet able to reason more deeply to solve problems. The distribution pattern of the graph also shows that learning interventions are needed to build advanced sustainability skills.

Competency levels are still moderate to low. This is evident in the holistic thinking indicator, where only 28.24% were able to answer correctly. On average, many students still find it difficult to relate environmental challenges to the interdisciplinary thinking presented in the case. Interdisciplinary thinking is necessary as a starting point for solving environmental problems (Sommier et al., 2022). Furthermore, students are quite capable of reflecting on the values and events they have experienced (HT3). The ability to reflect critically on oneself is necessary to fully understand the problem (Brunstein et al., 2018). However, when looking at the ability to communicate ideas, students still have difficulty explaining the problems they face. Therefore, strengthening is needed in the sub-indicators by giving assignments that combine interdisciplinary aspects and are presented in a challenging form.

Furthermore, when viewed from the conflict resolution indicator, it is known that the initial ability of students is at a moderate level (26.46%). The highest sub-indicator can be seen in the ability of students to identify

possible conflicts that arise in sustainable issues. Students are already able to consider future possibilities. The ability to consider future possibilities can be developed through a series of familiarisation with problems (Wijnia et al., 2024). This is in line with constructivist theory, namely that the combination of experience and knowledge improves students' abilities (W. Li et al., 2023). However, the sub-indicator of formulating realistic and optimal strategies received the lowest percentage score of 16.73%. This is because students have many doubts about making decisions. Therefore, to improve the ability to choose realistic solutions, simulation or role-play activities are needed in the learning model.

The uneven distribution of capabilities supports the argument that sustainable competencies develop progressively. To form a complex capability, learning interventions are needed that integrate holistic thinking and conflict resolution to support sustainable development.

Differences in student sustainability competencies based on differences in the length of study

The length of study indicates the amount of material that students have acquired. Previous studies have highlighted comparisons between the length of study and differences in competencies (Alshawi et al., 2023; Biancardi et al., 2023; Qi et al., 2023). However, no research has specifically highlighted the difference in the length of study with sustainability competencies. Before analysing the differences in students' initial abilities according to the length of study, the data were first tested for normality and homogeneity. The normality test used the Kolmogorov-Smirnov normality test. The results of the normality test can be seen in Table 6.

Table 6. Results of normality testing of initial sustainability competency data

Indicator	Semester	Kolmogorov smirnov		p (2 tailed)
		Statistical value	df	
HT	5	0,217	54	0,000
	7	0,130	44	0,049
CR	5	0,174	54	0,000
	7	0,168	44	0,003

(Source: Research Results, 2025).

Based on the results of the Kolmogorov-Smirnov normality test, it is known that all indicators have a sig p value of < 0.05. It can be concluded that the data is not normally distributed. This reflects heterogeneity in prior knowledge and readiness. Fifth-semester students showed higher statistical values than seventh-semester students, which means that there was higher variability among fifth-semester students, while seventh-semester students were more homogeneous, even though they were not normally distributed. Furthermore, the results of homogeneity using Levene's test can be seen in Table 7.

Table 7. Results of the homogeneity test of initial sustainability competency data

Indicator	F	df1	df2	P value (two tailed)
HT	7,357	1	96	0,008
CR	0,048	1	96	0,826

(Source: Research Results, 2025).

The results of the homogeneity data analysis show that the significance value of holistic thinking ability indicates that the data is not homogeneous (0.008<0.05). For the holistic thinking indicator, an F value of 7.357 with a p-value of 0.008 indicates an unequal variance between the two groups. This means that students' systemic and integrative thinking abilities are distributed at varying levels, reflecting differences in

academic ability and cognitive maturity. However, the conflict resolution indicator shows that the data is homogeneous with a significance value of 0.826>0.05. On the other hand, the conflict resolution indicator shows that there is relatively little difference between groups. Visually, this means that even though students differ in their systemic thinking abilities, they have a similar foundation in conflict-related competencies. The pattern of diverse homogeneity shows that holistic thinking and conflict-oriented thinking cognitive skills have different developmental paths in learning.

Based on the normality and homogeneity test data, it shows that the initial sustainability competency data is not normal and homogeneous. Therefore, to see the difference in sustainability competency abilities before treatment, a non-parametric Mann-Whitney U Test statistical analysis was used. The results can be seen in Table 8 below.

Table 8. Comparison of sustainability competencies among students based on the length of study

Indicator	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig (2 tailes)
HT	680.500	2165.500	-3.674	0.000
CR	556.500	2041.500	-4.580	0.000

Source: Research Results, 2025.

Table 8 shows the results of the Mann-Whitney U test used to compare the sustainability competencies of fifth- and seventh-semester students. Negative Z values (-3.674 and -4.580) indicate a shift in ranking scores. This means that one group systematically achieved higher scores than the others. Higher Z-scores on the CR indicator indicate a stronger imbalance, meaning that there is a greater difference in ability on the CR indicator. This is because academic experience or learning treatment has influenced students' ability to resolve conflicts. The results also show that there is a significant difference between fifth- and seventh-semester students in terms of holistic thinking and conflict resolution indicators, with a significance value of 0.000 ($p< 0.005$). The analysis results show that the length of study is closely related to sustainability competencies. Seventh-semester students have better competencies than fifth-semester students. It can be concluded that the longer students pursue their education, the more knowledge and learning experience they gain. Learning experiences gained in lectures can come from discussion lectures. In line with the research Annelin & Boström (2023), the integration of environmental learning into the curriculum can strengthen systemic thinking skills and understanding of the interrelationships between various aspects that affect the environment.

In terms of conflict resolution skills, seventh-semester students are more trained in identifying conflicts and providing sustainable solutions. This is supported by findings that emphasise that sustainable competencies develop through the learning process. Thus, seventh-semester students gain more learning and collaboration experiences during their lectures (Sattich et al., 2024).

The effect of the PBGL learning model on sustainability competencies

Before testing the effect of the PBGL learning model on sustainability competencies, prerequisite tests were conducted, namely normality and homogeneity. The normality test used the Kolmogorov-Smirnov test. The results can be seen in Table 9.

Table 9. Results of the normality test of data on the effect of PBGL on sustainability competencies

Indicator	Kolmogorov smirnov		p-value(two tailed)
	Statistical value	df	
Eksperimen	0.106	49	0.200
Kontrol	0.086	49	0.200

(Source: Research Results, 2025).

Based on the results of normality analysis, it is known that the significance value of the experimental and control groups is 0.200. This indicates that the data is normally distributed, p>0.05. The p-value is identical to the threshold value, indicating that the sustainability competency scores between the groups do not deviate from normality. The statistical value in the experimental group differs from that in the control group but is still within the normal range. This indicates that before further testing, both groups exhibit balanced distribution characteristics. Furthermore, the results of the homogeneity test using Levene's test can be seen in Table 10.

Table 10. Results of the homogeneity test of data on the effect of PBGL on sustainability competencies

t	df	F	Levene's statitistik
13.462	96	0,049	0.825

(Source: Research Results, 2025).

Levene's test results show that nilai t = 13,462 dengan df = 96. This means that the difference in means is highly significant between groups. The t-value indicates that the difference in scores is substantial. The Levene's statistic score is 0.825 (>0.05). Based on the homogeneity test results, it can be concluded that the data are homogeneous. The combination of homogeneous variance and a large t-value indicates observable differences in the learning effects using the PBGL model. Based on the prerequisite test, it can be concluded that the data is normally distributed and homogeneous. Thus, to determine the effect of the PBGL learning model on sustainability competencies, it can be analysed using an independent sample t-test. The T-test results can be seen in Table 11.

Tabel 11. Results of the independent sample T-test on the effect of PBGL on sustainability competencies

	t	df	Sig (2 tailed)	Mean Difference	Std error difference
N.gain	13.462	96	0.000	11.980	0.890

(Source: Research Results, 2025).

The results of the independent T-test show a significance value of 0.000 (p<0.05), which means that there is a significant difference between the mean n-gain of the experimental and control groups. The mean difference shows a value of 11.980, which means that the experimental group has a higher increase than the control group. Furthermore, the value of t = 13.462 shows that the t-test value is very large. These results show a big difference between the experimental and control groups. The relatively small standard error difference (0.890) indicates stable and consistent improvement among students. The experimental group showed significant improvement, indicating that the PBGL model contributed to accelerating the growth of sustainability competencies.

The results of the independent sample T-test confirm that the experimental group, which learned using the PBGL learning

model, experienced a higher increase in continuous competence compared to the control group. These findings are in line with recent reviews that learning using games designed through pedagogical aspects has a positive impact on learning outcomes and behavioural changes. The experimental group was taught to think systematically through the games provided. Likewise, the combination of games and the problem-based learning model strengthens students' knowledge transfer and understanding of complex problems. This is in line with research Čubela et al. (2023) and Tan & Nurul-Asna (2023), which states that a learning approach using games designed with the integration of pedagogical aspects effectively improves critical thinking skills, creativity, and awareness of complex sustainable environmental learning.

The research findings confirm that problem-solving learning influences sustainability competencies due to its systematic learning steps. Students are first introduced to environmental issues and begin to learn how to organise problems. Students are introduced to real-world problems that are interesting to solve. Then, in the initial investigation and information gathering phase, students are trained to think critically. As stated in the research Carrió Llach & Llerena Bastida (2022), critical thinking enables students to think factually. After collecting data, in-depth investigations are carried out, and the level of learning challenges is increased. Students take the opportunity to become emotionally involved and add complexity to the problems. This is reinforced by the findings of a study from Manzano-León et al. (2021) which states that games require levelling up to increase the ability and attractiveness of the problems offered. Game-based learning enables students to think systemically by involving them in environmental issues.

If the analysis is sharpened on the holistic thinking sub-indicator, the PBGL learning model influences the sub-indicator of communicating ideas (HT4). The results are shown in Figure 3 below.

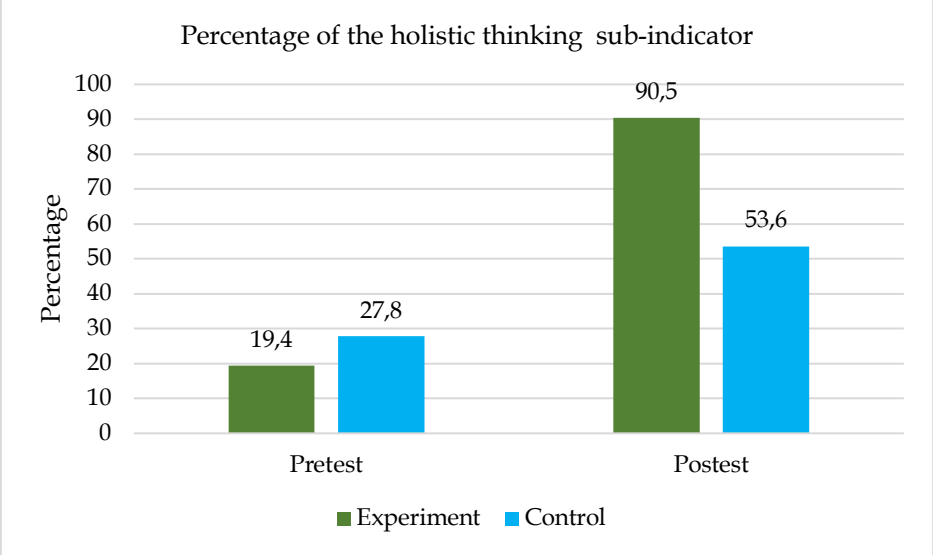

Figure 3. Diagram of holistic thinking indicator results in the experimental and control groups (Source: Research Results, 2025)

Based on Figure 3, it is known that the achievement of the holistic thinking indicator in the experimental and control classes. It is known that in the pretest score, the experimental class was far below the control class (19.4 < 27.8). However, after learning using PBGL, the holistic thinking score of the experimental class increased significantly compared to the control class (90.5 > 53.6). This confirms that learning using PBGL is effective in improving students' holistic thinking abilities.

Holistic thinking is a competency in the cognitive aspect that includes the ability

to view complex environmental issues from various perspectives. This ability also supports the ability to connect the factors that influence environmental conditions and integrate sustainability values into decisions (Karayol & Topsakal, 2025). Holistic thinking skills emphasise systematic, transdisciplinary, and reflective thinking skills. In line with the research (Yildiz Durak, 2020), it is confirmed that reflective thinking skills require students to have the ability to identify problems from various factors, including environmental, social, and economic factors.

The PBGL learning model is able to stimulate holistic thinking skills by combining problem-based learning and gamification. Gamification encourages students to explore problems further. The determination of levels in gamification creates challenges in learning and makes students hone their critical thinking skills in relation to the proposed solutions. In line with the research findings, the results of studies from Chen & Wu (2023) and Kalogiannakis et al. (2021) how that learning with games can improve critical thinking skills. Furthermore, the provision of rewards and level increases creates an adaptive learning experience and encourages emotional engagement. This is supported by findings which state that strategies in game-based learning can improve problem-solving and systems thinking skills that are relevant to sustainable competencies (Sulistianingsih & Mukminan, 2019).

When examined in more detail, holistic thinking, which is divided into four sub-indicators, experienced a significant increase in scores on average, in both in the two different groups. However, in terms of the ability to communicate ideas (HT4), the experimental class was more prominent than the control class. This is because in the PBGL model stage, there is a solution presentation stage, where students are trained to convey ideas, argue, and defend their ideas. The activity of presenting findings strengthens students' motivation to communicate. This is in line with previous research Crespí et al. (2022), which confirms that problem-based learning can improve communication and collaboration skills. The gamification element in learning makes it more enjoyable, thereby boosting students' confidence. As mentioned in the study Y. Li et al. (2019), confident students can hone their communication skills more.

When viewed from the results of the analysis of the conflict resolution sub-indicator, both two different groups of students experienced an increase. The percentage results of the conflict resolution indicator scores in the PBGL and conventional groups can be seen in Figure 4 below.

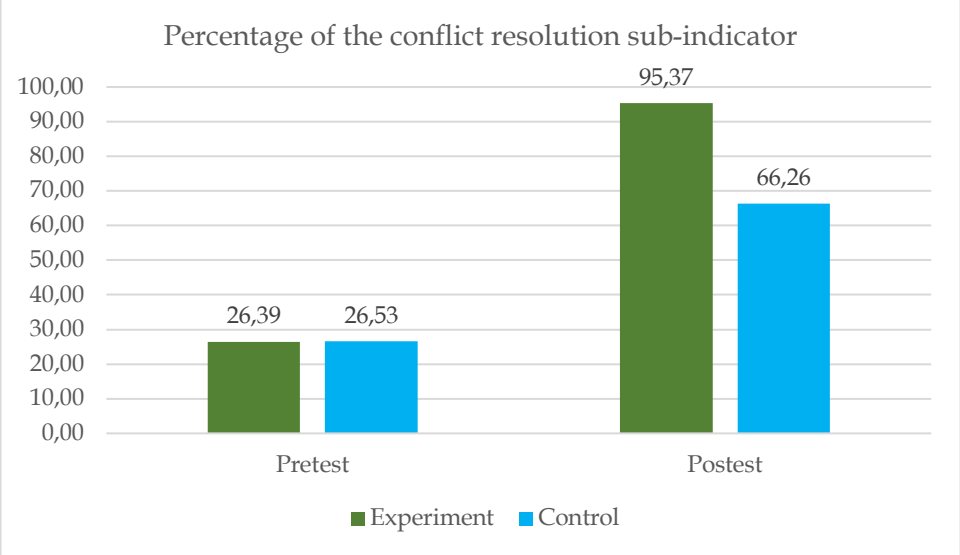

Figure 4. Diagram of conflict resolution indicator results in the PBGL and conventional group (Source: Research Results, 2025).

The results of research on conflict resolution indicators in general show that there was an improvement in ability in both groups. The abilities of the two different groups in the pre-test were relatively the same. This indicates similar initial competencies. However, in the experimental group using PBGL, there was a very significant increase (95.37), which was much greater than that of the control class (66.26). These findings indicate that the learning model using PBGL has a significant effect on students' conflict resolution abilities.

Conflict resolution in sustainability abilities includes the ability to negotiate, compromise, and think critically in finding the best strategy for solving environmental problems. Solving environmental problems that can be solved demonstrates a collaborative strategy so that problems are resolved without conflicts of interest (Sari et al., 2025).

The PBGL learning model has proven to be very effective in improving the ability to identify interrelated sustainability conflicts. This is because in the problem-oriented learning step, the problem is already presented through articles presented in class. This is reinforced by Islami et al. (2023), presenting real problems at the beginning of learning can improve students' ability to identify problems.

In terms of the ability to identify possible solution priorities, students demonstrated the ability to choose realistic solutions amid limitations. This was enhanced through organising and in-depth investigation activities. The challenges in the problems integrated into the green city development game encouraged students to explore solution scenarios and helped them to prioritise solutions. Research Hoalst-Pullen et al. (2021) states that in-depth investigation enables a better understanding of problems from various perspectives, thereby facilitating the determination of the best solutions.

Furthermore, the ability to formulate realistic strategies saw the greatest improvement in the conflict resolution indicator. Students were able to combine the theoretical knowledge they had acquired with the context of more realistic environmental issues and were able to provide realistic solutions. The evaluation and reflection step encourages students to evaluate the solutions they have provided, enabling them to better recognise successful solutions and develop critical thinking skills. This is confirmed by research Sattich et al. (2024), which found that learning that integrates games into practical, continuous learning can improve students' ability to formulate applicable solutions, particularly in the context of resource management. Furthermore, research Emihovich et al. (2020) states that the step of presenting solutions triggers strategic thinking through collaborative thinking, enabling the design of long-term solutions.

This study has three fundamental aspects that differ from previous studies. First, there have been many previous studies on PBL and gamification (Carrió Llach & Llerena Bastida, 2022; Jääskä et al., 2021; Khaldi et al., 2023; Sari et al., 2021; Sari, Ridhwan, Sahudra, Urfan, et al., 2025; Tan & Nurul-Asna, 2023; Zainuddin et al., 2020), namun sebagian besar penelitian tersebut but most of these studies have focused on improving learning outcomes, student engagement, and learning motivation. This study explicitly examines the impact of the PBGL model on sustainability competencies, with an emphasis on holistic thinking and conflict resolution. The research specifically highlights the influence of the PBGL model on sustainability competencies with an emphasis on holistic thinking and conflict resolution. In addition, the novelty itself lies in the syntax of the model, which is integrated into seven steps. Second, previous studies often highlight gamification to increase motivation and interest in learning (Kramar & Knez, 2025; Putra et al., 2020; Sattich et al., 2024b), but in this study, the gamification mechanism is combined with learning steps so that mission-based learning, level progression, and reflective evaluation can be seen from learning activities. Third, many studies related to testing conceptual models use experimental designs (Berger & Wyss, 2021; Rasiban et al., 2025; Tamam & Corebima, 2023), but the testing is limited to proof. This study includes a comparison between the length of study that allows for developmental readiness and the mastery of sustainable competencies. This aims to

provide material for consideration in implementing the PBGL model by looking at the preparation of students' abilities to accelerate the development of sustainable competencies.

CONCLUSION

The findings show that students' initial abilities in all sustainability competency indicators are still in the moderate and low categories. The findings are reinforced by the similarity in students' pre-test scores between the two different groups. This shows that students do not yet have the optimal ability to understand the interrelationships between issues. Students are also unable to think critically, holistically, and transdisciplinarily, so they do not yet have the ability to develop problem-solving strategies. This condition indicates the need for learning that can stimulate the improvement of students' sustainability competencies. Therefore, learning innovation is needed.

When viewed in terms of length of study, seventh-semester students have an advantage over fifth-semester students in terms of problem identification and critical thinking. Experience in collaborating in lectures shows a significant influence on students' ability to collaborate in problem-solving. However, when viewed in terms of final scores, the abilities of seventh and fifth-semester students are still relatively poor.

After receiving treatment using the PBGL learning model, an increase in sustainability competencies was seen in the experimental class compared to the control class. The application of the PBGL model had a significant effect on the holistic thinking and conflict resolution of students in the experimental class. In particular, there was a huge increase in the ability to formulate realistic problem-solving strategies. This shows that the PBGL model is able to train students to collaborate in considering solution priorities through various thoughts.

This study contributes to sustainable environmental learning. In addition, it also confirms that the PBGL model innovation is effective in strengthening sustainability competencies. This study is able to present the results of integrating gamification into the learning model, making it one of the learning model options that can be used as an instructional strategy to internalise sustainability values. In practical terms, this research is expected to be implemented in many environmental courses, both in geography education study programmes and other study programmes. However, this research has limitations, namely, limited generalisation because it was conducted at only one university. Another limitation is the quasi-experimental design, which has a limited time frame, making it impossible to generalise the long-term effects. In response to this limitation, it is hoped that the research subjects can be expanded to other universities so that the results can be more generalised. Furthermore, it is hoped that long-term research will be conducted to observe the long-term effects of implementing the model. In addition, the development of immersive technology can also be integrated, so further research is needed on the integration of immersive games in sustainability competencies.

ACKNOWLEDGMENT

This research was conducted in accordance with the internal funding group research grant scheme of Universitas Samudra, implemented by LPPM Universitas Samudra under contract number 240/UN54.6/PT.01.05/2025. In addition, we would like to express our deepest gratitude to the Geography Education Study Programme and all parties who assisted in the implementation of this research.

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