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Permaculture Gamification as Innovative Learning Strategy to Enhance Students' Collaboration Competency

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Abstract: Collaboration is a core competency to promote effective teamwork and prepare students for success in both academic and professional environments. Permaculture gamification learning has the potential to enhance students' collaboration competency. Permaculture is an artificial ecosystem that encourages sustainable agricultural practices. There is a noticeable gap in the literature on integrating gamification into permaculture learning to improve students' collaboration skills. Therefore, this study aims to investigate the students' collaboration competency improvement through the application of permaculture gamification as a learning strategy on ecosystem topics. This study used a quantitative research method with nonequivalent (pretest and posttest) control-group design. There are experimental group and control group, both groups take a pretest and posttest but only experimental group receives the treatment. The sample in this study consisted of 50 students from one high school in the city of Bandung. The students in the control group followed the regular learning process in the classroom. Meanwhile, the students in the experimental group followed the permaculture gamification learning. The instruments used in this study were collaboration assessment tools, including self-assessment, peer assessment, and observation rubric. Statistical t-test applied to analyze di difference on students collaboration competency outcomes after treatment. The N-Gain value was calculated to evaluate the effectiveness of the treatment to improve students' collaboration competency. The t-test results showed that there is a significant difference in students' collaboration competency between the two groups ($p = 0.04$). Permaculture gamification learning significantly improved students's collaboration competency ($p < 0.05$). Based on the N-Gain value, permaculture gamification learning has a higher impact on students' collaboration competency (N-Gain = 0.56) compared to the regular learning strategy (N-Gain = 0.40). It can be concluded that permaculture gamification learning can effectively improve students' collaboration competency.

Keywords: permaculture gamification, collaboration competency, ecosystem.

▪ INTRODUCTION

Collaboration is a fundamental skill that plays a crucial role in fostering productive teamwork. Many experts and organizations have developed collaboration competency frameworks to define, assess, and improve the particular skills required for effective teamwork and collective problem-solving (Barker Scott & Manning, 2022; Scoular et al., 2022). It highlighted the collaboration skills as the 21th century skills (Riaz & Din, 2023). Laar et al. (2020) stated that 21st-century skills as essential competencies required by individuals in both the education system and the workforce in the context of the current economic conditions. In the Indonesian curriculum, collaboration is emphasized, particularly within the "Merdeka Belajar" framework (Priyambodo & Wilujeng, 2023) to foster student independence and develop crucial 21st-century skills through project-based learning (Zhang et al., 2023) and group activities (Muti'ah et al., 2021).

According to UNESCO, collaboration is a key competency for sustainability (Rieckmann 2017). Collaboration competency defined as the abilities to learn from

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others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving (UNESCO, 2017). Many experts argue that collaboration is the top priority skills needed to achieve sustainability (Mariai et al., 2022; Browser at al., 2024). By developing these collaborative competencies, individuals and organizations can create more effective and inclusive solutions to address global sustainability challenges.

Previous studies examining students' initial collaboration competency profiles show that most students have collaboration competencies at a low to intermediate level (Hairida et al., 2021; Aufa et al., 2021). Some notable problems in the students' collaboration competency including free-riding (Kloppenburg et al., 2018), low-quality coordination among group members (Dietrichson et al., 2022), group conflict, and lack of leadership (Akhavan Tabassi et al., 2022). These problems need to be addressed through applied teaching strategies that can help students enhance their collaboration competency. Zamiri & Esmaeili (2024) argue that by incorporating structured collaboration activities and providing continuous feedback, educators can help students develop the necessary skills to work more efficiently and in teams. Implementation of the suitable teaching strategies can help teachers to enhance the students' particular competency.

The most popular and effective strategy to improve students' collaboration competency is through group projects and activities (Sirait & Amnie, 2023; Rodriguez-Salvador & Castillo-Valdez, 2023). The integration of game activities into the learning process can motivate students and make learning more enjoyable. Game-based learning has long been implemented in the learning activities. Game activities expose students to group dynamics which can help students to engage in meaningful discussions and exchange ideas (Georgopoulou, 2024). Martín-Hernández et al. (2021) concluded that the introduction and use of game elements with learning purposes could increase student engagement and motivation, improve academic performance, encourage interaction and socialization, and offer opportunities to develop autonomous learning skills.

Game-based activities are well-suited for outdoor learning (Prasetyo et al., 2023). It allows students to explore the surrounding environment through interactive experiences, fostering both engagement and a deeper understanding of the subject matter. The environment setting can be designed to support the learning process. Gamification in outdoor learning has been widely used as a method to engage students and enhance their learning experience (Zidan et al., 2024). Outdoor learning is often associated with environmental learning activities, as it provides opportunities for direct interaction with nature and fosters a deeper understanding of the environment (Hastika et al., 2024). By integrating game-based strategies, teachers can create more dynamic and immersive learning environments for the students.

In environmental education, permaculture is a popular term. Alakendu et al. (2024) define permaculture as a sustainable farming approach for the modern era that has been widely used. Permaculture serves as a valuable learning resource for environmental topics such as ecosystems that includes outdoor activities, allowing students to observe and analyze real-world objects and phenomena. Previous studies show that permaculture as a learning resource can promote education for sustainable development practice (Raynolds, 2022), support biodiversity learning (Najira et al., 2025), and environmental consciousness (Ozturk & Forsythe, 2024). Hands-on activities for studying ecosystems

provide experiential learning, helping to optimize students' understanding of the ecosystem concepts.

Based on the explanation above, permaculture gamification learning has the potential to enhance students' collaboration competency through the collaborative learning strategy. However, there is a noticeable gap in the literature regarding the integration of gamification into permaculture learning activities as a strategy to improve students' collaboration skills. Therefore, this study aims to examine how permaculture gamification learning can enhance students' collaboration competency. By examining the effects of this learning strategy, the study will provide valuable insights into the role of gamification in fostering collaboration competency among students. The findings could contribute to the development of more effective teaching strategies that promote collaborative learning across various educational settings.

▪ METHOD

Participants

The population in this study was tenth grade students from one high school in the City of Bandung. The sampling technique used was purposive sampling to obtain samples that align with the research objective and fulfill the required criteria. The sample of this study was 50 students, they were in two different classes with 25 students in each class. The students in the control group followed the regular learning process in the classroom. Meanwhile, the students in the experimental group followed the permaculture gamification learning.

Research Design and Procedures

The research method used in this study was quasi-experimental research which do not include random assignment of the participants (Fraenkel et al., 2023). This study used a quantitative approach with nonequivalent (pretest and posttest) control-group design. In this design, there are experimental group and control group, both groups take a pretest and experimental group receives the treatment (Creswell, 2014). The research design shown in Table 1. The initial stage of this research involved a literature review of previous studies on collaboration competency and permaculture gamification learning. Observations and interviews with the teacher were conducted to gather data on the learning process at the school. The preparation stage included the development of research instruments and instructional materials, such as lesson plans, learning resources, and the permaculture design. The research instrument examined by experts and revised based on experts advises.

Table 1. Nonequivalent (pretest and posttest) control-group design

Control group	Pretest	No treatment	Posttest
Experimental group	Pretest	Experimental treatment	Posttest

Both control group and experimental group took the pretest before the learning session. The students in the control group followed the regular learning process in the classroom. Meanwhile, the students in the experimental group followed the permaculture gamification learning. Each group participated in four learning sessions. Each groups explored two different landscapes to observe and learn about ecosystems and their respectives components. The students completed their assignments and engaged in

learning activities in groups. Both groups took the posttest after they completed all the learning sessions.

The control group explored the school area including mini park. The experimental group explored the permaculture area which include four main learning posts: gardening post, aquaponic post, composting post, and black soldier fly (Hermetia illucens) post. The students were organized into groups, each consisting of five members. Each group competed in game-based learning activities. The game series, themed "EcoRush Championship" included four challenges. In the first challenge, the groups competed to identify as many biotic and abiotic components as they could find in the gardening post. In the second challenge, the groups formed a food web and ecological pyramid based on the ecosystem components they identified in the first game. For the third challenge, the groups competed to identify the black soldier fly's life cycle and create a model using real specimens. Finally, in the fourth challenge, the groups designed a sustainable permaculture system. The games were played over the course of four learning sessions. The winning group was determined by the total points they accumulated during the games, and the two best groups were awarded prizes. There was also an individual competition at the end of each learning sessions. The students participated individually in the game by answering the evaluation questions about the concepts they had just learned on Kahoot!, a web-based platform. The best player in the individual competition was determined by the cumulative points and was also awarded a prize.

Instrument

The instruments used in this study were non-test instruments including self-assessment, peer assessment, and observation rubric. The instrument was developed based on the aspects of collaboration competency according to UNESCO (2017). Self assessment and peer assessment were structured questionnaires using a 4-point Likert scale, ranging from strongly agree (4), agree (3), disagree (2), and strongly disagree (1). Some items used unfavorable statements to avoid biased responses. Meanwhile, the observation rubric was used to assess students' collaboration competency across five aspects: effective group communication, empathy, empathic leadership, conflict management, and participatory problem-solving. The validity and reliability of self-assessment and peer assessment calculated using IBM SPSS Statistics 27. The initial instrument consisted of 26 items each; based on the validity test results from both assessments, six items were eliminated. As a result, a total of 20 items considered valid ($p < 0.05$) were included in the self assessment and peer assessment. The self-assessment and peer assessment instruments were considered reliable, with Cronbach's alpha values of 0.92 and 0.94, respectively. The collaboration aspects and indicator shown in Table 2. Each indicator consists of two items or statements.

Table 2. Collaboration aspects

No	Aspect	Indicator
1	Effective group communication	Build effective communication with group members.
		Refelcting on the group work.
2	Empathy	Able to adapt and show respect for group members.
		Able to understand the attitudes and actions of group members.
3	Empathic leadership	Divide tasks according to the capabilities of team members.
		Assist team members with difficulties they face.

4	Group conflict management	Able to resolve differences among group members.
		Maintain a shared vision and understanding.
5	Participatory problem solving.	Offer problem-solving solutions.
		Contribute to achieving common goals.

Data Analysis

The level of students' collaboration competency was determined by referring to the collaboration assessment rubric developed by National Center for Improvement of Educational Assessment (2023). There are four categories of collaboration competency, namely, beginning, emerging, developing, and demonstrating. The final collaboration competency score of each student was determined by the average of the cumulative scores from the self-assessment, peer assessment, and observation rubric, with equal weighting. The improvement of each students' competency was analyzed using N-Gain by Hake (1999). Based on the Shapiro-Wilk normality test, the data from control group ($p = 0.54$) and experimental group ($p = 0.09$) were considered to have a normal distribution ($p > 0.05$). The homogeneity test using Levene's test ($p = 0.23$) showed that the data from both groups have equal variances ($p > 0.05$). As both assumptions for the parametric test were met, an independent samples t-test was applied to compare the students' collaboration competency learning outcomes between the two groups.

This study was conducted in accordance with research ethics, including obtaining voluntary consent from participants, ensuring data confidentiality, and using the data solely for academic purposes. A research permit was submitted and approved by the appropriate institution before the study was carried out.

▪ RESULT AND DISSCUSSION

The permaculture gamification learning allows students to engage in group activities. The permaculture setting consists of four learning stations as the learning resources for ecosystem topics. The students explore each learning station to learn about ecosystem concepts through game activities. Meanwhile, the students in the control group explore the school area to identify and observe the surrounding ecosystems. Outdoor learning was implemented as the initial stage of the learning process for both groups to introduce students to the fundamental principles of the ecosystem concept, specifically the interactions between biotic and abiotic components. Pretest and posttest results of the students' collaboration competency are shown in Table 3. Both groups showed a slight improvement on their collaboration competency based on the pretest and posttest results.

Table 3. Students' collaboration competency based on the pretest and posttest results

Data Comparison		**Control Group**		**Experimental Group**	
Number of students		25		25	
Data type		Pretest	Posttest	Pretest	Posttest
Collaboration aspects					
Aspect I	Mean	84.21	89.08	83.87	92.09
	Standard deviation	11.18	6.47	9.04	8.02
Aspect II	Mean	80.92	84.01	82.68	89.73
	Standard deviation	11.28	5.70	8.92	8.85
Aspect III	Mean	79.98	82.57	78.54	85.07
	Standard deviation	8.59	5.92	11.21	7.15

Aspect IV	Mean	74.35	81.44	79.07	85.50
	Standard deviation	8.37	6.45	9.03	6.71
Aspect V	Mean	75.98	83.86	77.90	84.17
	Standard deviation	16.13	7.63	9.64	10.31
Average	**Mean**	**79.09**	**84.19**	**80.41**	**87.31**
	Standard deviation	**8.70**	**5.26**	**7.55**	**5.34**

The pretest results shown in Figure 1 indicate that the initial level of students' collaboration competency was already at a good level. In the control group, the collaboration competency of more than half of the students were in the demonstrating category. Meanwhile, in the experimental group, the number of students in the developing and demonstrating categories was almost the same. The data in Figure 1 shows the cumulative score from the five aspects of collaboration competency. Based on the observation, some students did not actively participate in the group discussion. Many students also expressed that they were not confident in becoming the group leader. This phenomenon has also been identified in college students (Abd Rahim et al., 2023), in the professional field (Hancock et al., 2021) and especially among women (Perets et al., 2023). This indicates that there are opportunities to enhance and optimize students' collaboration competency.

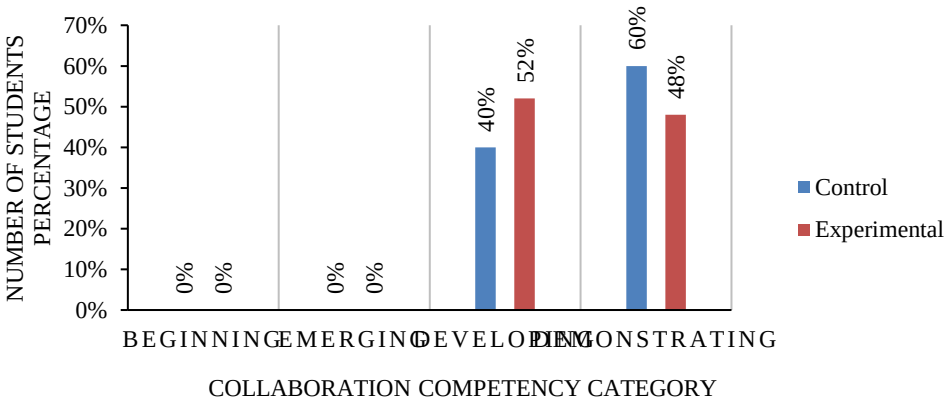

Figure 1. The initial level of students' collaboration competency

Although many students demonstrated adequate collaboration skills based on their pretest results, they still faced challenges in specific areas such as leadership and conflict management. Previous studies have revealed similar findings. For instance, Omodan & Skosana (2023) found that although students often exhibit a high level of collaboration skills, certain components such as effective communication, role negotiation, and conflict management remain underdeveloped. Similarly, Sun (2023) noted that although students engaged effectively in a collaborative simulation game, they still lacked the negotiation and communication skills necessary to fully benefit from group interactions. These findings indicate that although students' general collaboration skills are relatively good, certain specific aspects are still lacking and remain essential for the students to strenghten.

Both the control and experimental groups participated in group activities during the learning sessions. The gamification elements, such as rewards, score achievements, and group competition, were only applied to the experimental group. Game activities were

designed to increase engagement, motivate participation, and encourage collaboration among members. Capatina et al. (2024) stated that game activities can increase participant engagement and inspire them to perform better in their tasks. Yu & Cardoso-Leite (2020) also stated that game-based activities have been employed as an effective strategy to enhance collaboration skills, fostering teamwork, communication, and problem-solving among participants. In addition, several factors can influence collaboration and determine the success of teamwork, such as team communication and feedback (Salcinovic et al., 2022), decision making and leadership (Salmons, 2019) and proper distribution of tasks among group members to ensure equal work (Scheel at al., 2019).

The learning activities in each session integrate game-based activities. Points were awarded to the team that successfully completed the game challenge. At the end of the learning sessions, one best group and three standout players will be recognized and awarded rewards, such as additional exam points and treats. The best group is selected based on their performance in completing the tasks, while individual winners are chosen based on their evaluation scores. The giving of rewards is intended to acknowledge the students' achievements and encourage continued engagement. A longitudinal study has shown that rewards are highly valued by students, serving as an outside reinforcement that can enhance their motivation to complete assignments and maintain good grades (Wang, 2021; Hussain et al., 2023). Beside the positive impact, Chen (2023) argued that the reward system can cause students to lost the ability to intrinsically motivate themselves. Therefore, teachers need to thoroughly examine the use of the reward system in the learning process.

The posttest data presented in Figure 2 shows that students in both the control and experimental groups demonstrated progress in their collaboration competencies. All of the students in the experimental group were in the demonstrating category. Meanwhile some students in the control group were in the developing category. Both the developing and demonstrating categories are considered to represent a medium-high level of competency. In line with this result, Nyahuye & Steyn, (2020) found that gamification can increase students' teamwork skills. This is related to the learning process, where in each learning session, the students complete their assignments as a group. The integration of game activities fosters collaboration, engagement, and motivation, allowing students to actively work together towards achieving shared goals.

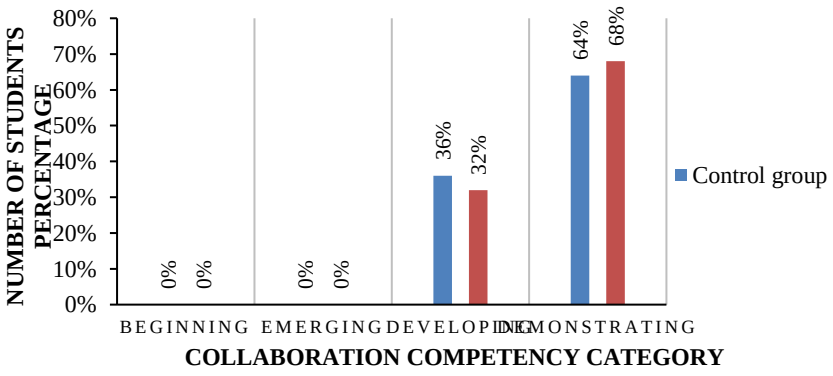

Figure 2. Level of students' collaboration competency after completing all learning sessions

Outdoor learning, as the initial learning stage, plays an important role in providing students with hands-on experiences that enhance their understanding of the ecosystem key concepts (Ayotte-Beaudet et al., 2024; Hastika et al., 2024). The first learning station in the permaculture area is a mini garden. Each group of the students were assigned the task of observing and identifying the components of the ecosystem present in the garden. Each ecosystem component correctly identified by the students will be awarded points. This competition between groups motivates students to collect as many ecosystem components as possible. Consistent with these results, Jääskä et al. (2022) stated that the integration of game and competition provides strong motivation for students, contributing to an improvement in their performance. In addition, Aggrawal & Boowuo (2023) argued that the team competition encourages collaborative learning and help students understand the significance of teamwork in achieving desired outcomes.

Several game activities designed to facilitate the learning process. Several aspects need to be considered when designing a game-based activities to support the students' learning. Adipat et al. (2021) argue that the fundamental concepts in designing game-based learning include the practicality of the game activities, ensuring that the game is both enjoyable and meaningful for students. After the students identify the biotic and abiotic components, the next challenge is for them to form a food chain that could occur in the ecosystem based on its biotic components. In the aquaponic and composting learning station, the students were assigned the task to draw the biogeochemical cycle that occurs within the systems. In the aquaponic and composting learning stations, the students were assigned the task of drawing the biogeochemical cycles that occur within the systems. Lastly, in black soldier fly farm learning station, students were assigned the task of compiling the BSF life cycle by identifying the morphology of each life stage of the flies. Students' work is then examined to determine the best one based on the cumulative points.

Students appear to be more engaged in task division among group members as a strategy to win the competition. The students also seem to show excitement in completing their tasks. Game-based learning enhances student attention and engagement, making them more motivated and excited to learn (Atoulloh et al., 2024; Omarov et al., 2024). Panjaitan & Dasari (2024) also stated that the game-based learning approach boosts students' interest and facilitates collaboration skills. Additionally, the interactive game-based learning applied in the permaculture gamification encourages active participation among group members, allowing students to develop social and teamwork skills.

Intervention of time limit for the students to complete their group assignments can enhance their group management skills and foster effective communication. The students tend to become more organized, prioritize tasks, and collaborate efficiently to meet deadlines. Fang & Maglio (2024) stated that setting deadlines can increase work completion rates and task performance but reduce creativity. Avoyan et al. (2023) also argued that teams experiencing high time pressure are more likely to experience miscoordination and struggle to reach consensus compared to teams under low time pressure. Therefore, the time limit needs to be set thoughtfully, taking into account the students' abilities and the difficulty of the task.

The collaboration competency emphasizes effective communication, empathy, leadership, group management skills, and participatory problem-solving. These aspects need to be addressed and taught to the students. The teacher should be mindful of the

group dynamics as stated by Putri et al. (2019) that the teacher's role goes beyond educating, teaching, and training; it also involves assessing the classroom situation and understanding the students' ability in receiving lessons. The teacher must also remind the students of the importance of each aspect of collaboration competency. Fung (2022) findings revealed that students who participated in group work with teacher guidance demonstrated the greatest sense of collaborative success. Therefore, the teacher's guidance is essential in directing the working process of each group.

Several challenges encountered in utilizing permaculture as a learning resource were extensive time preparation and financial costs. The same challenges were also highlighted by Ozturk and Forsythe (2024), who stated that the costs and time required to build a permaculture pose barriers to its implementation in classrooms. Beside that, permaculture gamification learning required outdoor activity. Outdoor learning offers numerous educational benefits, but several challenges may arise prior to its implementation. Weather becomes a key factor, as unfavorable conditions may cancel outdoor learning plans. Some students appeared uncomfortable in sunny weather and while walking on muddy surfaces in the outdoor environment. As stated by Liu & Li (2022), one major obstacle in outdoor learning is weather unpredictability, which can disrupt activities and impact safety and learning outcomes. Additionally, the outdoor environment can be highly stimulating, sometimes leading to distractions that reduce students' focus and engagement. Those challenges affect class time management, requiring teachers to be flexible, adjust lesson plans on short notice, and implement effective strategies to maintain student engagement.

Collaborative learning helps students to better understand the topics they are studying through group discussions and the exchange of ideas. Diverse experiences and knowledge among group members can contribute to effective mutual learning. Groups consisting of members with prior knowledge of aquaponics and black soldier fly farming concepts tend to complete their tasks more quickly, which also supports other group members in developing a better understanding of the concepts. It is aligned with previous research by Ben-Simon and Reichenberg (2022), which suggests that the exchange of diverse perspectives enriches students' understanding. Additionally, collaboration improved the quality of students' group projects in designing a permaculture system that promotes sustainability as a solution to ecosystem degradation. Students' diverse experiences and knowledge regarding sustainable practices contribute to the development of innovative ideas, such as a permaculture system that integrates chicken farming and black soldier fly farming simultaneously, bio water treatment, and other sustainable solutions.

The N-Gain of both groups highlights that each learning approach has a distinct impact on students' collaboration competency. As shown in Figure 3, the experimental group demonstrates a slightly better improvement. Several students in the experimental group show a high improvement, while most students in the control group show a low improvement. Nevertheless, both the regular learning (N-Gain= 0.40) and permaculture gamification learning (N-Gain= 0.56) can enhance the students' collaboration competency at certain levels. The results of the independent samples t-test ($p = 0.04$) indicate a significant difference in the collaboration competency between the control and experimental groups, suggesting that permaculture gamification learning is significantly more effective in enhancing students' collaboration competency.

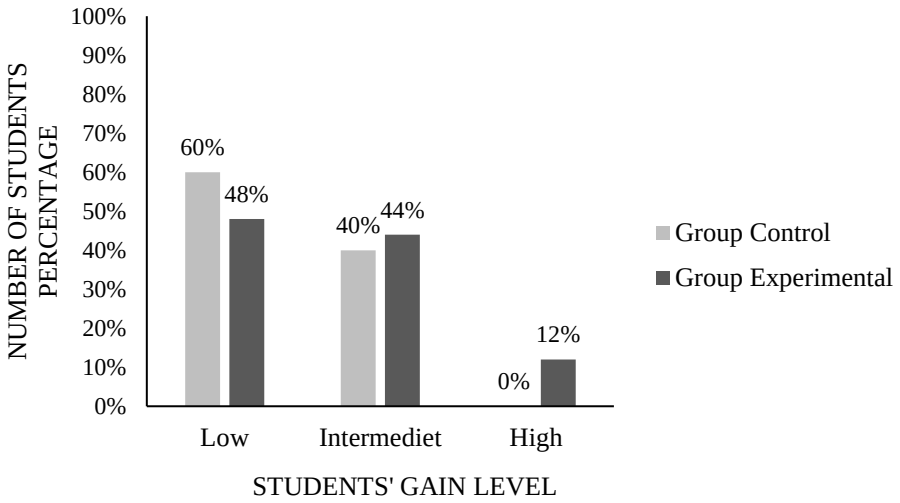

Figure 3. Comparison of gain percentage level from control and experimental groups

Permaculture gamification learning allows students to work collaboratively in groups to complete shared tasks. Groups in which all members actively participate in discussions tend to demonstrate higher performance. Similarly, Masek et al. (2021) highlighted that active participation of group members in discussions contributes positively to the achievement of shared goals. Furthermore, groups with clear task divisions among members also easily succeed in every game. Additionally, van der Meulen and Aivaloglou (2021) noted that a proper task division among group members enhances collaboration efficiency, as students assign tasks based on expertise and preferences leading to a more effective teamwork. The integration of gamification elements in the experimental group appears to have played a significant role in enhancing students' collaboration competencies, despite the fact that students in the control group also participated in group activities. Group activities not only enhance concept understanding but also play a crucial role in developing students' social skills and character. Kohn (2024) stated that group activities and collaborative learning foster effective team leadership. Game activities in permaculture gamification learning contribute to enhancing the five aspects of collaboration competency.

▪ CONCLUSION

Permaculture gamification learning has a positive impact on students' collaboration competency. The learning process which includes games activities in each learning session contributes to enhancing effective communication, empathy, leadership, group management skills and participatory problem-solving of the students. By adding gamified elements such as rewards, score achievements, and group competition, students are more likely to stay engaged and motivated to put forth their best effort in completing tasks. It can be concluded that permaculture gamification learning is notably effective in improving students' collaboration competency. The findings of this study suggest that the integration of gamification elements into the learning process enhances students' learning activities.

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