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Gamification-Based Discovery Learning: Impact on Biology Students' Cognitive Outcomes and Motivation

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Abstract: This study aimed to investigate the impact of a gamification-based learning model on learning outcomes and student learning motivation in ecosystem materials, as well as to explore the relationship between learning motivation and learning outcomes. A quasi-experimental pretest-posttest non-equivalent control group design was used. The subjects were tenth-grade high school students selected using cluster random sampling. Data was collected using validated tests and questionnaires and analyzed using ANCOVA and Pearson Product-Moment correlation tests. Hypothesis testing was done with the ANCOVA test and the Pearson Product-Moment correlation test. The results showed that the gamification-based discovery learning model had a significant effect on both learning outcomes (sig. = 0.028) and learning motivation (sig. = 0.00) with a moderate effect size. Furthermore, a strong positive correlation was identified between learning motivation and learning outcomes after the model was applied. This research concludes that the integration of gamification elements into the discovery learning model is an effective pedagogical approach for fostering student motivation and improving academic achievement in secondary education.

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INTRODUCTION

The educational goals that are successfully achieved can be measured through learning outcomes assessed in the learning assessment. Learning outcomes are defined as the competencies and skills obtained through the learning process (Molstad & Karseth, 2016). Learning outcomes show the students' abilities after completing the learning process. However, the PISA 2022 report shows that, due to the pandemic, global learning outcomes have declined. The achievement of learning outcomes in Indonesia is still relatively low, below the OECD average (OCDE, 2023).

Biology learning requires the active involvement of students because the materials presented are generally complex and require critical and analytical thinking skills. An important material is the ecosystem, which emphasizes the relationship between components, the interaction between components, and the impact of changes in a component on the entire ecosystem. Understanding this material is not just memorization; students need to build conceptual and applicative understanding through interactive learning. However, learning practices in the classroom are still dominated by a teacher-centered approach that does not provide space for students to actively participate in the learning process. This is exacerbated by students' low motivation to learn, as well as the lack of implementation of learning reflections that can help students understand their learning process. This leads to low student involvement, which contributes to declining learning outcomes.

Meanwhile, the growing use of games across various groups, including teenagers, creates opportunities to develop interesting and relevant learning strategies by leveraging game elements in education. Gamification is an approach that adopts game elements, such as points, badges, levels, challenges, awards, and leaderboards, into learning activities to improve student engagement, motivation, and learning outcomes (Kapp, 2012). Several studies have shown that gamification can create a fun, competitive, and challenging learning environment, thus having a positive impact on student engagement, motivation, and learning outcomes (Alshammari, 2020; Pangaribuan et al., 2022; Sailer & Sailer, 2021;

Salah & Alzaghal, 2023).

One of the learning models that is in line with the principle of active student involvement is discovery learning, which is based on the theory of constructivism. The discovery learning model emphasizes the activity of searching, exploring, and finding concepts independently so that students are actively involved in building their knowledge (Tohari & Rahman, 2024). According to this theory, students find it easier to understand and remember concepts by actively participating in processing information through hands-on learning experiences (Khoiriyah & Murni, 2021). Previous studies have reported that students' learning outcomes improve significantly following the implementation of the discovery learning model (Erna et al., 2024; Malau & Nainggolan, 2024; Sukmasari, 2024; Sulastri et al., 2024). Furthermore, the integration of gamification into discovery learning has been found to effectively enhance learning outcomes, increase students' motivation, and create a more enjoyable and conducive learning environment (Aldalur & Perez, 2023).

However, the effectiveness of gamification in educational settings remains inconclusive. Several studies have reported that the implementation of gamification does not significantly affect students' learning outcomes or learning motivation (Aji & Napitupulu, 2018; Pehlivan, Fatma and Arabacioglu, 2023). These contradictory findings suggest that the effectiveness of gamification may depend on the learning context, subject matter, and instructional design employed. Furthermore, empirical evidence regarding the implementation of gamification-based discovery learning in biology, particularly on ecosystem topics at the senior high school level, remains limited.

Therefore, this study aims to determine the difference in the influence of gamification-based discovery learning models and discovery learning models on student learning outcomes and motivation. In addition, to find out whether there is a relationship between learning motivation and learning outcomes after applying the gamification-based discovery learning model. The results of this research are expected to contribute to the development of innovative, interactive, and effective biological learning strategies.

METHOD

This study employed a quantitative approach using a quasi-experimental design to investigate students' cognitive learning outcomes, learning motivation, and the relationship between cognitive learning outcomes and learning motivation. A pretest-posttest non-equivalent control group design was utilized to examine the effects of gamification-based discovery learning on students' cognitive learning outcomes and learning motivation. The independent variable was the learning model, consisting of gamification-based discovery learning implemented in the experimental group and conventional discovery learning implemented in the control group. The dependent variables were students' cognitive learning outcomes and learning motivation (Figure 1).

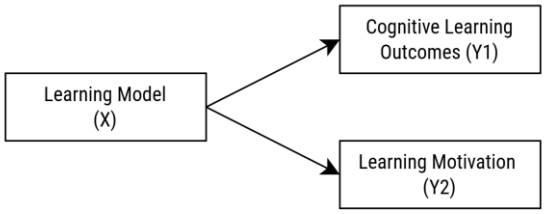

Figure 1. Conceptual Framework

The participants consisted of 72 tenth-grade students from a public senior high school in Central Java, Indonesia. Participants were selected using a cluster random sampling technique and were assigned to either the experimental group (n = 36) or the control group (n = 36). Each group received a different instructional treatment to examine the effects of the learning models on biology learning, particularly on ecosystem topics. The experimental group was taught using gamification-based discovery learning, whereas the control group received conventional discovery learning.

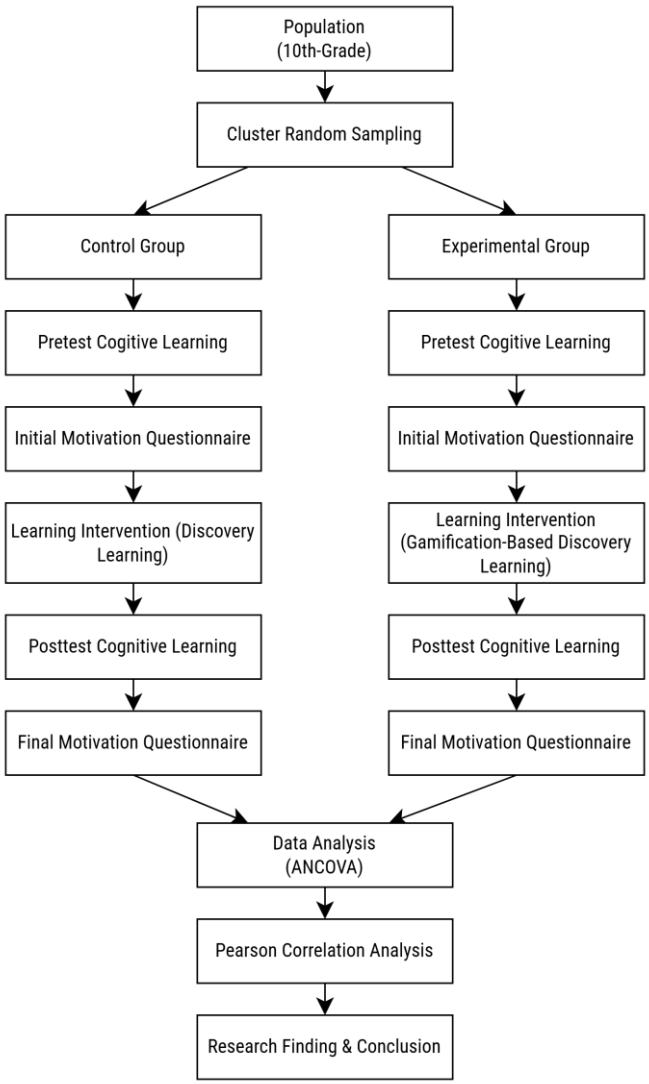

Figure 2. Research Procedure for Gamification-Based Discovery Learning

Data was collected through validated tests and questionnaires. Cognitive learning outcomes were assessed using seven essay questions developed from Bloom's Taxonomy levels C1–C6. The instrument was designed to evaluate students' understanding of ecosystem concepts across increasingly complex cognitive processes, ranging from remembering to creating. Cognitive learning outcome indicators have been presented in Table 1. The learning motivation questionnaire was developed by adapting instruments of Dayel et al. (2018). Responses were collected using a four-point Likert scale ranging from strongly disagree (1) to strongly agree (4). The questionnaire measured six dimensions of learning motivation. Learning motivation indicators have been shown in Table 2.

Table 1. Indicator of Cognitive Learning Outcomes

Cognitive Level	Indicator
C1	Identifying factors affecting ecosystem productivity
C2	Explaining biogeochemical cycles
C3	Calculating energy transfer efficiency
C4	Analyzing ecosystem components in biogeochemical cycles Analyzing ecosystem productivity data
C5	Evaluating impacts of ecosystem disturbances
C6	Creating solutions to ecosystem problems

Table 2. Indicator of Learning Motivation

Aspect	Indicator	Description
Value	Intrinsic Goal Orientation	Students' internal interest in learning
	Extrinsic Goal Orientation	Motivation driven by external rewards
	Task Value	Perceived usefulness of learning tasks
Expectancy	Control of Learning Beliefs	Belief that effort influences achievement
	Self-Efficacy for Learning and Performance	Confidence in completing learning tasks
Affect	Test Anxiety	Emotional responses toward assessment

All instruments used in this study underwent both content validity and construct validity testing. Content validity was evaluated by two experts in Biology Education. The experts assessed the instruments in terms of content relevance, alignment with learning objectives, language clarity, and appropriateness for tenth-grade students. Revisions were made based on the validators' feedback before the instruments were subjected to construct validity and reliability testing and subsequently administered to the research participants. The construct validity of the cognitive learning outcomes test and the learning motivation questionnaire was examined using Pearson Product-Moment correlation analysis. Items were considered valid if they demonstrated a significant positive correlation with the total score ($p < 0.05$). Reliability was assessed using Cronbach's alpha coefficient, with values greater than 0.60 indicating acceptable reliability.

The data collected were analyzed using SPSS version 25. Prior to hypothesis testing, prerequisite analyses were conducted to assess normality, homogeneity of variances, linearity, and homogeneity of regression slopes. Analysis of Covariance (ANCOVA) was used to determine the influence of the models, while Pearson Product-Moment correlation analysis was used to examine the relationship between motivation and learning outcomes. Furthermore, to determine the magnitude of the influence of interventions on motivation and learning outcomes, it was analyzed using the interpretation of the size effect, which refers to Ariyani & Prasetyo (2020), namely very large ($d > 0.8$), large ($0.5 < d \leq 0.8$), medium ($0.2 < d \leq 0.5$), and small ($0 < d < 0.2$). Meanwhile, to determine the level of relationship between motivation and learning outcomes, it was analyzed using the interpretation of correlation coefficients, referring to Sugiyono (2011), namely very low (0.00–0.199), low (0.20–0.399), medium (0.40–0.599), high (0.60–0.799), very high (0.80–1.000).

RESULT AND DISCUSSION

This study aimed to determine the differences in the influence of gamification-based discovery learning models on student learning outcomes and motivation. In addition, to find out the relationship between learning motivation and learning outcomes. Based on the analysis of the test data and the questionnaire, the following results are presented below.

The Influence of Gamification-Based Discovery Learning Models on Cognitive Learning Outcomes

The learning outcomes of the cognitive domain in this study were developed based on indicators that refer to the Bloom Taxonomy, which includes cognitive levels C1-C6. These indicators serve as the basis for developing test instruments, including up to seven descriptive questions used to measure students' comprehensive understanding of ecosystem materials (Table 1). Test instruments were administered before and after the learning treatment to measure the changes in student learning outcomes. Table 3 presents the results of descriptive statistical analysis of the pretest-posttest values of the control and experimental classes.

Based on the descriptive statistics in Table 3, the average pretest scores of the control and experimental classes showed a difference of 1.45 points, which indicates that the initial abilities of the two groups were relatively equal. After the treatment, the average post-test score of the experimental class was 4.63 points higher than the control class. Meanwhile, the increase in value after treatment in the experimental class was higher, at 37.709, while in the control class it was 31.637. This difference suggests a positive impact of gamification on cognitive learning outcomes. The standard deviation for both classes increased from pretest to posttest, indicating a wider variation in learning outcomes after the treatment. To test the hypothesis, further analysis was conducted using ANCOVA; the results are

presented in Table 4.

Table 3. Descriptive Statistics of Cognitive Learning Outcomes

Statistical Results	Control Class		Experimental Classes	
	Pretest	Posttest	Pretest	Posttest
N	36	36	36	36
Minimum	4,7	33	14,2	38
Maximum	66,6	90,4	52,3	90,4
Average	33,544	65,181	32,097	69,806
Standard Deviation	11,5447	13,8881	9,4636	13,7483
Variance	133,280	192,878	89,559	189,016

Before the ANCOVA test, the data met the assumptions of normality, homogeneity, linearity, and homogeneity of regression slope. Based on the three tests, the data met the assumptions for the hypothesis test. The ANCOVA test results (Table 4) showed a significance value of 0.028, which is less than 0.05, indicating a significant difference in the influence between the two learning models on cognitive learning outcomes. While both models improved student outcomes, the gamification-based approach had a greater influence, as evidenced by the larger increase in scores from pretest to posttest in the experimental group. This finding is supported by research showing that classes that apply gamification have higher learning outcomes than control classes. These findings are supported by research (Alshammari, 2020), that classes that apply gamification show higher learning outcomes than traditional classes.

The magnitude of the influence, or effect size, from the ANCOVA test was 0.399. Based on the interpretation by Ariyani & Prasetyo (2020), this value is classified as a medium category because it falls within the interval of $0.2 < d \leq 05$. The moderate effect is attributed to other factors influencing learning, such as motivation, emotional condition, and students' learning styles (Ekowati, 2019). However, a moderate effect still indicates the success of the applied learning strategy.

Table 4. ANCOVA Test Results of the Cognitive Learning Outcomes

Source	Sig.	*Partial Eta Square*	Information	Conclusion
Corrected Model	0,00	0,399	Sig. < 0.05	H1 accepted
Learning Outcomes	0,028	0,068	Sig. < 0.05	

The integration of gamification with the discovery learning model is an added value for improving student learning outcomes. Research by Huang et al. (2020) and Sailer & Homner (2020), also prove that gamification in learning has a significant influence on cognitive learning outcomes. According to Aldalur & Perez (2023)The application of the discovery learning model combined with gamification elements plays a role in arousing students' enthusiasm for learning, creating a fun learning experience, increasing concentration, and student involvement during the learning process. Some studies showed the use of elements like points, leaderboard, challenge, reward, and badges can improve learning outcomes, motivation, and student engagement (Alsadoon et al., 2022; Chans & May, 2021; Velázquez-García et al., 2024). The findings of this study align with the theory of constructivism, which emphasizes the importance of student involvement in discovering the their own understanding.

The discovery-learning, gamification-based model encouraged students to engage in independent exploration and problem-solving in a fun and challenging environment. According to Kapp (2012), gamification impacts on science learning. The learning carried out is oriented towards the active participation of students in their learning activities, finding information through theories and real phenomena in life. This research invites students to explore the interaction of ecosystem components in the biogeochemical cycle, ecosystem productivity, and ecosystem changes. Therefore, the integration of gamification with the discovery learning model allows students to contextually understand the concept of ecosystems. This approach is supported by findings that demonstrate an increase in learning outcomes following the implementation of contextual learning (Lotulung et al., 2018). Other findings also reinforce

the findings of the study, that the integration of the discovery learning gamification-based model encourages active involvement of students in building their knowledge (Tohari & Rahman, 2024), as well as having a positive effect on student motivation and learning outcomes (Smirani & Yamani, 2024).

The Influence of Gamification-Based Discovery Learning Models on Learning Motivation

Students' learning motivation is obtained through motivational instruments adapted from Dayel et al. (2018) which refers to a social-cognitive motivation model that includes three main aspects of learning motivation: expectations, values, and affective. Learning motivation indicators have been developed based on these three aspects. The questionnaire was administered before and after the treatment. Table 5 presents the results of the statistical analysis of student learning motivation.

Table 5. Descriptive Statistics of Student Learning Motivation

Statistical Results	Control Class		Experimental Classes	
	Beginning	End	Beginning	End
N	36	36	36	36
Minimum	77	67	67	81
Maximum	108	105	112	114
Average	92,56	89,61	94,53	95,03
Standard Deviation	7,951	7,338	9,941	7,424
Variance	63,225	53,844	98,828	55,113

Based on the descriptive statistics in Table 5, the average initial motivation scores in the control and experimental classes differed by 1.97 points, suggesting that students' initial motivation was generally equivalent. After the treatment, the experimental class showed an increase in motivation by 0.5 points, while the control class experienced a decrease of 2.95 points. This indicates that the application of the discovery learning gamification-based model positively increases students' learning motivation in experimental classes, despite the relatively small increase.

Based on the decrease in the standard deviation at the initial motivation, the final motivation shows a narrower data distribution, with reduced variation. The decreased variation in data indicated a more homogeneous final motivation score than the initial motivation score in both the control and experimental classes. The decrease in the standard deviation indicates a narrower data distribution and a more homogeneous final motivation score across both classes, suggesting that differences in motivation between students tended to be lower after the treatment.

Before the ANCOVA test, the data met the assumptions of normality, homogeneity, linearity, and homogeneity of regression slope. The ANCOVA test results (Table 6) showed a significance value of 0.002, which is <0.05. This means there was a significant difference in the influence between the two learning models on learning motivation. The gamification-based discovery learning model had a greater influence on increasing student motivation compared to the standard discovery learning model. This result is reinforced by research showing that gamification increases motivation through student involvement in the classroom (Alshammari, 2020).

A significant influence or effect size in the ANCOVA test results is indicated by the partial eta square on the line-corrected model, which is 0.447. This value is classified as a medium effect because it falls within the interval of $0.2 < d \leq 0.5$. The effect of treatment is classified as moderate because it is influenced by several factors, including the classroom environment, teachers, and students' intrinsic motivation (Ullah et al., 2013). Therefore, although the effect is moderate, it demonstrates the success of the learning strategies applied to increase learning motivation.

Table 6. ANCOVA Test Results of the Learning Motivation Score

Source	Sig.	*Partial Eta Square*	Information	Conclusion
Corrected Model	0,00	0,447	Sig. < 0.05	H1 accepted
Learning Motivation	0,002	0,127	Sig. < 0.05	

The integration of gamification into the discovery learning model helps increase students' motivation to learn. The application of game elements in gamification learning is designed to create a

more engaging (Lampropoulos & Sidiropoulus, 2024) and a fun learning experience. Game elements such as missions, challenges, points, rewards, and leaderboards have a positive impact on increasing students' active participation. The use of these elements creates a balanced learning dynamic between competition and collaboration. These results are supported by previous research showing that students who are actively involved in learning are influenced by the existence of awards, feedback, and self-awareness of progress during the learning process (Khoshnoodifar et al., 2023). Therefore, the elements of the game, as applied to the discovery-learning, gamification-based model, play a role in fostering students' motivation to learn. According to Velázquez-García et al. (2024), students' motivation to learn increases after using badge elements. Badge elements act as a sign of recognition for students who have successfully completed a task. Points can also increase student engagement and motivation to learn (Chans & May, 2021). Element leaderboard: the role of students in arousing the spirit of competition to achieve maximum points. According to Alsadoon et al. (2022), leaderboard increases competitiveness with open assessments so that they have a positive impact on student engagement and learning motivation. Lampropoulos & Sidiropoulus (2024) argued that the integration of gamification in learning can increase students' intrinsic and extrinsic motivation. Several other studies also support the idea that gamification can increase learning motivation (Alsadoon et al., 2022; Bharti, 2023; Su & Cheng, 2015).

The elements of the game, integrated into the discovery learning model, encourage the achievement of learning goals, thereby strengthening students' sense of responsibility for their learning process. One element that can increase the sense of responsibility is punishment. Element punishment was applied to provide consequences for students' negligence or non-involvement in the learning process. This is also strengthened by the fact that punishment is used to train self-regulation in students, who increase their sense of responsibility (Kapp, 2012). Based on observations made during the learning process, the students of the experimental class showed a higher level of enthusiasm and engagement than those in the control class. The active involvement of students is evident in various learning activities, such as group discussions, presentations, and Q&A sessions. This phenomenon is supported by research conducted by Baah et al. (2024), who found that gamification can improve motivation to learn, work, interest, and communication skills.

The results of this study are in line with the principles of the Self-Determination Theory. This theory emphasizes that a person's intrinsic motivation can grow optimally if three basic psychological needs are met: autonomy, competence, and relatedness (Deci & Ryan, 1985). Autonomy in gamification-based learning is facilitated by giving students the freedom to choose learning challenges using the Ecochess Board. This strategy gives students control during their learning process (Bharti, 2023). In addition, elements such as a leaderboard, rewards, points, and badges encourage competence, thereby increasing competitiveness among students. Collaboration between students in completing missions and challenges to achieve common goals according to aspects of relatedness or connectivity (Sailer & Sailer, 2021).

The increased learning motivation associated with the application of gamification in social-cognitive theory is supported by the presence of self-efficacy. According to Sitzmann (2011), gamification improves self-efficacy and retention. Self-efficacy, a high level of success, indicates that a person has high motivation. Biology learning on ecosystem materials teaches students to study the surrounding events associated with existing theories, making learning more contextual. According to Lotulung et al. (2018), contextual learning motivates students to understand materials that are relevant and applicable to real life. Therefore, based on research findings and theories aligned with model integration, Discovery Learning Gamification has been shown to significantly increase students' motivation to learn across various levels of education and teaching materials.

The Relationship Between Learning Motivation and Learning Outcomes

The relationship between learning motivation and student learning outcomes after being treated with a gamification-based discovery learning model was examined using a *Pearson* Product-Moment correlation. Before this hypothesis test is conducted, a prerequisite test is performed, including normality and linearity tests. Once the data met the assumptions of normality and linearity, the analysis was continued using a Pearson product-moment correlation test. The following results of the correlation tests are presented in Table 7.

Table 7. Correlation Coefficient between Learning Motivation and Learning Outcomes

Correlation	Sig.	*Pearson Correlation*
Learning Motivation and Learning Outcomes	0,00	0,641

The results of the correlation test showed a significance value of 0.00 < 0.05, it can be concluded that there is a significant relationship between the two variables. A correlation coefficient value of 0.641 shows a positive relationship between learning motivation and the learning outcome variables. This indicates that a one-way relationship that strengthens learning motivation plays an important role in students' success in achieving optimal learning outcomes. The results of the study are also strengthened by the high level of relationship, in the range of 0,60–0,799. Several studies relevant to these findings, prove the correlation between motivation and student learning outcomes (Bharti, 2023; Nugraha et al., 2021; Velázquez-García et al., 2024). The findings indicate that the higher the motivation to learn, the higher the learning outcomes (Nugraha et al., 2021). Other research also reinforced the idea that learning motivation affects learning outcomes (Purba et al., 2023).

Learning motivation is a driving factor for students to be actively involved during the learning process, which can have an impact on learning outcomes (Chans & May, 2021). Active student involvement is a determinant of learning motivation and learning outcomes. This is supported by *Self-Determination Theory* explains the importance of meeting the three psychological needs to foster student engagement and motivation to learn (Bharti, 2023). In addition, it is also supported by social-cognitive theory, which states that self-efficacy is an important component in increasing student involvement during the learning process. Students with high self-efficacy generally show greater involvement in the learning process and greater perseverance when facing academic challenges. It has also been mentioned by (Sitzmann, 2011), that gamification in learning increases the effect of increasing self-efficacy and retention. The challenge element applied in gamification-based learning builds students' confidence when they successfully complete a challenge. This is in line with previous research showing a relationship between self-efficacy, motivation, learning, and learning outcomes (Schunk & Pajares, 2009).

The findings of this study have implications for biology educators, demonstrating that gamification-based discovery learning can be implemented as an alternative instructional strategy to create more interactive and engaging learning environments. This approach may support students' active involvement, motivation, and understanding of complex biological concepts such as ecosystems.

This study has several limitations that should be acknowledged. First, the participants were limited to 72 tenth-grade students from a single senior high school in Central Java, Indonesia. Therefore, the findings may not fully represent students from different educational backgrounds or regions. Second, this study focused only on ecosystem topics in biology. Thus, the effectiveness of gamification-based discovery learning may vary when applied to other biological concepts or different subjects. Third, the intervention was conducted over a limited instructional period (three sessions), which may limit the evaluation of the long-term effects of gamification-based discovery learning on students' motivation to learn and cognitive outcomes.

CONCLUSION

This study concludes that the implementation of gamification-based discovery learning significantly affects students' cognitive learning outcomes and learning motivation in ecosystem learning. The results of the ANCOVA indicate that students who received gamification-based discovery learning achieved significantly higher cognitive learning outcomes than those who received discovery learning without gamification elements. In addition, the implementation of gamification-based discovery learning also significantly improved students' learning motivation. Furthermore, the correlation analysis showed a positive relationship between learning motivation and cognitive learning outcomes, indicating that students with higher learning motivation tended to achieve better learning performance. These findings suggest that integrating gamification elements into the discovery learning model can provide an engaging learning environment that supports both cognitive achievement and students' motivation in biology learning. Future research is recommended to investigate the implementation of gamification-based

discovery learning across different biological topics or other subjects, educational levels, and learning contexts to examine its broader applicability. Further studies may also consider longer intervention periods and additional measurement approaches to evaluate the long-term effects of gamification on students' learning motivation and academic achievement.

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