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# The Effectiveness of Gamified Collaborative Physics Learning on Concept Understanding and Student Engagement in Physics Learning

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***Abstract***

*Physics learning at the high school level frequently faces challenges related to low student engagement and conceptual difficulties caused by abstract content and conventional instructional approaches. This study aims to evaluate the effectiveness of Gamified Collaborative Physics Learning on the conceptual understanding and student engagement of high school students. Utilizing a quasi-experimental method with a pretest-posttest control group design, the research involved two classes selected through cluster random sampling. The research instruments included a two-tier multiple-choice conceptual understanding test, a student engagement questionnaire (covering behavioral, emotional, and cognitive aspects), and a collaborative activity observation sheet. The results indicate that the experimental class achieved a significant improvement in conceptual understanding with an N-gain score of 0.74 (high category), substantially outperforming the control class which only reached 0.49 (medium category). Furthermore, the average student engagement score in the experimental class reached 4.25 (high category), demonstrating that the integration of gamification elements—such as points, badges, and leaderboards—effectively triggers active participation and reduces the "free rider" phenomenon in group work. The implications of this study emphasize that the synergy between gamification and collaborative learning is not merely an entertainment element but a robust pedagogical strategy for creating an interactive, challenging learning environment that strengthens students' in-depth knowledge construction in the digital era.*

***Keywords:*** *Gamified Collaborative Physics Learning, Conceptual Understanding, Student Engagement, Physics Learning.*

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## 1. INTRODUCTION

Physics, as a branch of the natural sciences, is characterized by the need for deep conceptual understanding and strong mathematical representation skills (Munfaridah et al., 2021; Bao & Koenig, 2019; Sujito et al., 2021). However, in secondary school settings, physics is often perceived by students as an abstract, difficult, and less relevant subject to their everyday lives (Chala et al., 2020; Ekici, 2016; Cermik, 2020). The complexity of concepts such as motion, force, and energy is often not adequately supported by contextual and interactive instructional approaches, making it difficult for students to construct meaningful understanding (Podschuweit & Bernholt, 2018; Nie et al., 2019; Papadouris & Constantinou, 2016). At the same time, the rapid development of digital technology has transformed the ways in which younger generations interact with information, making them increasingly accustomed to visual, interactive, and immediate digital environments (Lahiri, 2020; Burghal et al., 2020). Nevertheless, the integration of technology into physics education remains largely limited to the use of presentation media or simple simulations that tend to be unidirectional, and therefore have yet to fully accommodate students' diverse learning needs (Banda & Nzabahimana, 2023; Rejekiningsih et al., 2023; Rincon-Flores et al., 2024).

These conditions may contribute to declining student motivation and engagement in the learning process (Verawati & Nisrina, 2025; Radulovic et al., 2023; Ramma et al., 2018). Low levels of *student engagement* constitute one of the major challenges in physics education, as students frequently assume the role of passive recipients of information rather than active participants in the construction of knowledge (Muna & Kalam, 2021; Hodges, 2020; Pitterson et al., 2016). Limited engagement not only affects classroom dynamics but also has direct implications for students' ability to develop a deep understanding of physics concepts (Bigozzi et al., 2018; Fernandez, 2017). Although collaborative learning approaches have been widely adopted as a potential solution, their implementation in practice has not always been effective (Le et al., 2018; Al-Samarraie & Saeed, 2018). This limitation is partly attributable to the absence of mechanisms that can ensure equitable individual participation within groups, resulting in a situation in which only some students actively contribute while others tend to rely on their teammates.

Previous studies have attempted to address these challenges through the implementation of *gamification* in physics education, which has been shown to enhance students' motivation and interest in learning (Tolentino & Roleda, 2019; Gaurina et al., 2025; Ferreira et al., 2019). Nevertheless, most existing studies have primarily focused on motivational outcomes or general learning achievement, with relatively limited attention to student engagement as a multidimensional construct. Furthermore, the integration of gamification with collaborative learning remains relatively underexplored, particularly in terms of simultaneously examining students' conceptual understanding and engagement. These two variables are closely interconnected and play a critical role in determining the effectiveness of learning. This research gap highlights the need for an innovative instructional approach that is not only visually appealing and interactive but also capable of fostering meaningful and measurable collaboration.

Building on these problems and research gaps, the present study proposes a *Gamified Collaborative Physics Learning* approach as an innovative solution for physics education. This approach integrates game elements, such as points, badges, leaderboards, and challenges, into a collaborative learning framework. Through this design, students are encouraged not only to achieve individual learning goals but also to actively contribute to their groups in addressing complex physics problems. The social interactions fostered within an environment that combines competition and collaboration are expected to substantially enhance student engagement while strengthening conceptual understanding through discussion, peer interaction, and meaning negotiation. Accordingly, this study is important for empirically examining the effectiveness of the proposed approach in improving the quality of physics learning at the secondary school level.

## 2. METHODS

This study employed a quantitative approach using a quasi-experimental design to examine the effectiveness of *Gamified Collaborative Physics Learning* in improving the conceptual understanding and student engagement of students at SMA Negeri 48 Jakarta. The study adopted a *pretest-posttest control group design* involving two classes selected through *cluster random sampling*. The experimental group received instruction based on collaborative gamification, whereas the control group received conventional instruction. The research procedure consisted of a pretest, an instructional intervention implemented over several sessions, and a posttest to comprehensively assess changes in students' learning outcomes and engagement. The population comprised 864 students enrolled at SMA Negeri 48 Jakarta, while the study sample consisted of 72 students.

The research instruments included a two-tier multiple-choice test designed to assess students' conceptual understanding, which had undergone validity and reliability testing; a student engagement questionnaire using a Likert scale covering the dimensions of *behavioral, emotional,* and *cognitive engagement*; and an observation sheet used to monitor students' collaborative activities during the learning process. Data analysis began with prerequisite tests, including tests of normality and homogeneity. These were followed by an *independent-samples t-test* to determine differences between the experimental and control groups, as well as an N-Gain analysis to measure the extent of improvement in students' conceptual understanding.

## 3. RESULT AND DISCUSSION

The results of the study indicate that the implementation of *Gamified Collaborative Physics Learning* had a significant effect on improving students' conceptual understanding and *student engagement*. Quantitatively, the mean posttest score of the experimental group was higher than that of the control group, indicating that the integration of gamification into collaborative learning can enhance the quality of physics learning outcomes. This finding was further supported by the N-Gain scores, which fell within the high category, demonstrating that the instructional intervention not only improved students' final achievement scores but also resulted in substantial gains from their initial level of understanding. In addition, the questionnaire results revealed that student engagement in the experimental group was higher, particularly in terms of active participation and cognitive engagement. The results of the study are presented in Table 1 below.

**Table 1.** Comparison of Learning Outcomes and Student Engagement

| Variabel | Kelas Eksperimen | Kelas Kontrol | Keterangan |
|---|---|---|---|
| Mean Pre-Test Score | 45.20 | 44.75 | Relatively comparable |
| Mean Post-Test Score | 85.60 | 72.30 | Higher in the experimental group |
| *N-Gain* | 0.74 (high) | 0.49 (moderate) | Significant improvement |
| *Student Engagement* | 4.25 (high) | 3.40 (moderate) | Higher engagement in the experimental group |

This finding is consistent with the findings of Park and Kim (2021), who reported that gamification elements such as points, badges, and leaderboards can significantly enhance students' intrinsic motivation and learning engagement. Furthermore, gamification mechanisms operate by establishing a reward system that provides students with a progressive and achievement-oriented learning experience. Points earned through each learning activity serve as indicators of progress, enabling students to monitor their development in a tangible manner (Cardoso et al., 2016; Llorens-Largo et al., 2016). Badges provide recognition for specific achievements, thereby fostering a sense of accomplishment and enhancing students' confidence in learning (Gooch et al., 2016). Meanwhile, leaderboards promote healthy competition among students, which not only increases participation but also encourages students to continuously improve their performance.

In the context of collaborative learning, gamification elements influence not only individual motivation but also strengthen social interactions among students (Bilgin & Gul, 2020; Slamet & Meng, 2025; Akgul & Guler, 2025). Group-based competition can encourage students to support one another, engage in discussions, and contribute actively toward achieving shared goals. Thus, gamification enhances not only behavioral engagement but also cognitive engagement through collaborative problem-solving processes (Huang et al., 2019). This effect makes the learning environment more dynamic, interactive, and student-centered, thereby contributing directly to improved conceptual understanding (Andini, 2024; Zainuddin et al., 2020).

More specifically, the effectiveness of this approach can be explained through several interconnected pedagogical mechanisms. First, the provision of immediate feedback within the gamification system enables students to identify errors and promptly revise their understanding. This finding is consistent with Afify (2018), who emphasized that timely and specific feedback is one of the most influential factors in improving learning outcomes. Second, the collaborative learning structure creates *positive interdependence*, in which group success depends substantially on the contribution of each individual member. This condition can effectively minimize the *free-rider* phenomenon and promote individual accountability. Consequently, students are not only socially engaged but are also motivated to understand the learning material in order to make meaningful contributions to their groups.

Third, the integration of game elements into learning can create psychological conditions conducive to achieving a *flow state*, in which students become fully immersed, focused, and engaged in the learning process. This finding is consistent with Oliveira et al. (2022), who demonstrated that an appropriate balance between challenges and individual abilities can generate optimal learning experiences. In the present study, progressively structured game-based challenges enabled students to remain motivated without becoming overwhelmed by the complexity of physics concepts. Furthermore, social interactions within groups strengthened the process of knowledge construction through discussion and meaning negotiation, which is consistent with the principles of social constructivism in education.

The findings of this study are also consistent with previous research demonstrating that gamification in science education can significantly enhance student engagement and learning outcomes (Khan et al., 2017; Kalogiannakis et al., 2021). Previous studies have highlighted that the integration of game elements into instruction can create learning environments that are more engaging, interactive, and oriented toward students' learning experiences (Rahmawati, 2025). However, most of these studies have treated gamification primarily as an individual learning strategy focused on personal motivation, without fully leveraging the potential of social interaction in the learning process (Rodrigues et al., 2021). Therefore, the present study provides a more comprehensive contribution by systematically integrating collaborative elements into the instructional design, thereby not only enhancing motivation but also strengthening knowledge construction through peer interaction.

The effectiveness of this approach suggests that gamification should not be regarded merely as an entertainment-oriented strategy (*edutainment*), but rather as a pedagogical approach grounded in strong cognitive and social principles (Rabah et al., 2018; Siripipatthanakul et al., 2023). In this context, gamification operates through the combination of adaptive challenges, reward systems, and continuous feedback, which can stimulate higher-order cognitive activity. When integrated with collaborative learning, students are encouraged not only to pursue individual learning goals but also to engage in discussion, argumentation, and meaning negotiation. This process aligns with the social constructivist perspective, which emphasizes that knowledge is constructed through interaction and shared experiences, ultimately resulting in deeper and more durable conceptual understanding.

Furthermore, the integration of gamification and collaboration also contributes to strengthening the affective and social dimensions of learning (Maraza-Quispe et al., 2024). A learning environment that combines competition with collaboration can create an atmosphere that is simultaneously challenging and supportive, enabling students to feel more motivated, confident, and emotionally engaged in the learning process. This condition directly contributes to enhanced *student engagement*, encompassing behavioral, emotional, and cognitive dimensions. Thus, learning is transformed from a predominantly one-way process into an active learning experience that engages multiple dimensions of students' learning.

The implications of these findings suggest that innovative and technology-enhanced physics instruction should adopt a holistic approach that balances cognitive, social, and affective dimensions of learning. Teachers should not merely function as information providers but should serve as facilitators who design meaningful learning experiences through the strategic integration of technology and appropriate instructional approaches. By optimizing the synergy between gamification and collaboration, physics instruction can become more engaging, relevant, and effective in fostering students' conceptual understanding and sustaining their engagement over time.

## 4. CONCLUSION

This study concludes that the implementation of *Gamified Collaborative Physics Learning* was significantly effective in improving students' conceptual understanding and *student engagement* at the secondary school level, as evidenced by an N-Gain score of 0.74 (high category) and a mean student engagement score of 4.25 (high category), both of which exceeded those of the control group. This effectiveness was driven by the synergy between gamification elements, such as points, badges, and leaderboards, and collaborative learning mechanisms that provided immediate feedback, fostered positive interdependence among group members, and facilitated the emergence of a *flow state* when solving complex physics problems. Theoretically, this integration demonstrates that gamification functions not merely as an entertainment element but as a powerful pedagogical strategy for minimizing the *free-rider* phenomenon and strengthening knowledge construction through dynamic social interaction. Therefore, this approach is recommended as an innovative instructional strategy for educators seeking to create physics learning environments that are more interactive, challenging, and relevant to the characteristics of students in the digital era

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