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Innovation in Science Learning with Gamification PhET Interactive Simulation at Senior High Schools in South Tangerang

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ABSTRACT

This community service initiative aimed to enhance digital literacy among high school science teachers by providing training in the use of PhET-based interactive learning media. The primary issue addressed was the teachers' limited skills in integrating technology into science instruction, which negatively impacted student engagement and understanding of scientific concepts. The approach involved participatory training methods, including workshops, hands-on sessions, and ongoing mentoring. Conducted over four weeks in a blended learning format, the program engaged 25 science teachers from Waskito High School. The training significantly improved teachers' abilities to utilize digital simulations, especially in physics topics like electricity, motion, and energy. Post-training evaluations revealed that 85% of participants could independently design and apply interactive media in their teaching. Additionally, students showed increased enthusiasm and active participation in science lessons following the implementation of these tools. Overall, the program highlights the effectiveness of focused digital literacy training in enhancing the quality of science education.

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INTRODUCTION

The problem faced by partner communities, in this case high school science teachers in South Tangerang, is their limited ability to utilize digital technology as an innovative learning medium. Most teachers still employ conventional learning methods dominated by lectures, resulting in one-way learning interactions and limited opportunities for students to actively explore concepts. This condition leads to low learning motivation and student engagement, as well as difficulty understanding abstract science concepts such as force, motion, energy, electricity, chemical reactions, and biological phenomena (Bell et al., 2008; Bybee, 2013; Slavin, 2020; Ministry of Education, Culture, Research, and Technology, 2022).

The transformation of education in the era of the Industrial Revolution 4.0 and Society 5.0 requires teachers to have integrated pedagogical, professional, and digital competencies to create learning that adapts to technological developments (Mishra & Koehler, 2006; Koehler et al., 2013). The Technological Pedagogical Content Knowledge (TPACK) framework explains that the success of digital learning depends not only on technological mastery but also on the ability to integrate technology with pedagogical strategies and comprehensive mastery of the teaching material (Mishra & Koehler, 2006; Koehler et al., 2013). However, various studies in Indonesia show that teachers' implementation of TPACK still faces various obstacles, including limited training, low digital literacy, and minimal use of interactive learning media (Rahmadi, 2019; Hidayat et al., 2021).

One alternative solution that can be implemented is the use of PhET Interactive Simulations, an interactive simulation tool developed by the University of Colorado Boulder. PhET provides a virtual learning environment that allows students to conduct experiments directly through computer simulations, allowing abstract concepts to be visualized concretely without the need for a complete physical laboratory (Perkins et al., 2006; Moore et al., 2014). Various studies show that the use of PhET can improve conceptual understanding, scientific thinking skills, science process skills, and student learning outcomes compared to conventional learning (Wieman et al., 2010; Finkelstein et al., 2005; Rutten et al., 2012).

In addition to the use of simulation media, 21st-century learning also demands the implementation of strategies that can increase student motivation. One emerging approach is gamification, which incorporates game elements such as points, levels, badges, leaderboards, challenges, and rewards into learning activities without changing the substance of the material (Deterding et al., 2011; Kapp, 2012; Werbach & Hunter, 2012). Gamification has been shown to increase intrinsic motivation, student engagement, collaboration, and student persistence in completing learning tasks (Hamari et al., 2014; Sailer et al., 2017; Zainuddin et al., 2020).

The integration of gamification with PhET Interactive Simulations provides a more meaningful learning experience because students not only observe the simulation but also receive challenges, feedback, rewards, and opportunities to explore concepts independently. This approach aligns with constructivist theory, which states that knowledge is actively constructed through learning experiences and interactions with the environment (Piaget, 1972; Vygotsky, 1978; Slavin, 2020). From Vygotsky's perspective, the use of digital media such as PhET serves as a mediation tool that helps students reach their Zone of Proximal Development (ZPD) through exploratory, collaborative, and teacher-led scaffolding activities.

This community service program is designed using a participatory training approach through workshops, hands-on activities, mentoring, group discussions, and classroom implementation. Teachers not only gain knowledge on the use of PhET Interactive Simulations and gamification concepts but are also guided in developing innovative learning tools in the form of teaching modules, Lesson Plans (RPP)/Teaching Modules, Student Worksheets (LKPD), assessment instruments, and interactive simulation-based learning scenarios. This practice-based training model is considered more effective in improving teacher professional competence than purely theoretical training (Desimone, 2009; Darling-Hammond et al., 2017).

This program is expected to enable high school mathematics (MI) teachers in South Tangerang to develop more innovative, interactive, contextual, and student-centered learning. The implementation of PhET Interactive Simulations-based gamification is expected to improve the quality of the learning process, learning motivation, critical thinking skills, problem-solving skills, and student learning outcomes in various MI subjects (Arends, 2012; Bell et al., 2008; Rutten et al., 2012; Ministry of Education, Culture, Research, and Technology, 2022). Furthermore, this activity is also expected to build a sustainable teacher learning community so that digital learning innovations can continue to develop in line with the demands of the Independent Curriculum and 21st-century learning.

RESEARCH METHODS

This program targets subject teachers, particularly mathematics and natural science teachers, at Waskito High School in South Tangerang. Teachers are the primary target group because they are agents of change in learning, implementing technology-based innovations and gamification in their respective classrooms. Students are the indirect beneficiaries of these learning innovations, particularly in improving motivation and understanding of science concepts. The total number of community service participants consists of 11 mathematics and natural science teachers (Mathematics, Physics, Chemistry, and Biology).

This program was implemented at Waskito High School, located in Serpong District, South Tangerang City, Banten Province. The location was selected based on the school's readiness in terms of ICT facilities, openness to learning innovations, and accessibility for the community service team. The implementation period lasted two months, from May to June 2026, encompassing planning, training, implementation, mentoring, and evaluation of results.

This community service program was implemented through four systematic stages: (1) Preparation and Planning Stage: Identification of teacher needs through interviews and initial questionnaires. Development of training modules and learning designs based on PhET Interactive Simulations and a gamification approach. Coordination with the school and preparation of a detailed activity plan. (2) Training and Workshop Phase: Implementation of training for teachers on the use of PhET media and learning gamification strategies. Hands-on practice sessions to design interactive simulation-based teaching media. The training was conducted in two one-day sessions. (3) Implementation and Mentoring Phase: Teachers implemented the innovative learning that had been designed in their respective classes via Zoom. The service team provided assistance during implementation and provided input for improvements. This process lasted one day. (4) Evaluation and Reflection Phase: Data collection through reflective discussions with partner teachers to evaluate the success and challenges of implementation. Preparation of a final report and documentation of best practices.

The service process was carried out in a participatory and collaborative manner, involving teachers as active subjects. The approach used was an educational action research approach that includes a repeated cycle of planning, action, observation, and reflection. The data analysis techniques used were as follows: (1) Qualitative data (classroom observations, teacher reflection journals, and interviews) were analyzed using thematic analysis, identifying patterns, themes, and categories from the narratives. (2) Quantitative data (questionnaire results and student formative tests) were analyzed using descriptive statistics, such as averages, achievement percentages, and pre-post training comparisons.

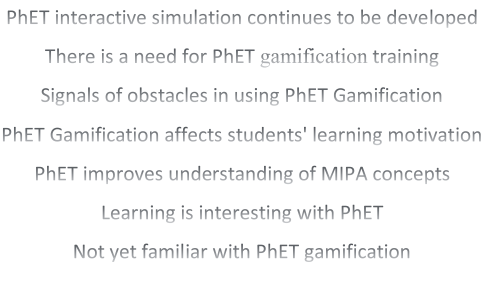
The service team consisted of: one team leader, responsible for general planning, activity coordination, and final evaluation. Five team members, each responsible for training in the use of PhET media and designing learning gamification, as well as for communication with schools and supporting classroom implementation. Throughout the program, the service team was active in designing the training, providing direct classroom support, conducting observations, and facilitating reflective discussions with teachers.

The success of this service program was measured through several key indicators, including: (1) Improved teacher competency in designing and implementing PhET and gamification-based learning, measured through pre-post tests and practical observations. (2) The level of student involvement in the learning process, measured through observation sheets and questionnaires. (3) The final product is prepared in the form of PhET-based teaching materials that are ready to be replicated. (4) Replication plan, where partner schools commit to disseminating the results of good practices to other schools in their network.

RESULTS AND DISCUSSION

A. Result

Waskito High School is a formal educational institution located in South Tangerang. It is currently developing and continuously improving the quality of learning, particularly in Mathematics and Natural Sciences (MIPA). Prior to the community service activities, observations and interviews were conducted regarding the PhET Simulation gamification. These observations were given to 11 teachers at Waskito High School, including mathematics, physics, chemistry, biology, and geography. The results are as shown in the following diagram:



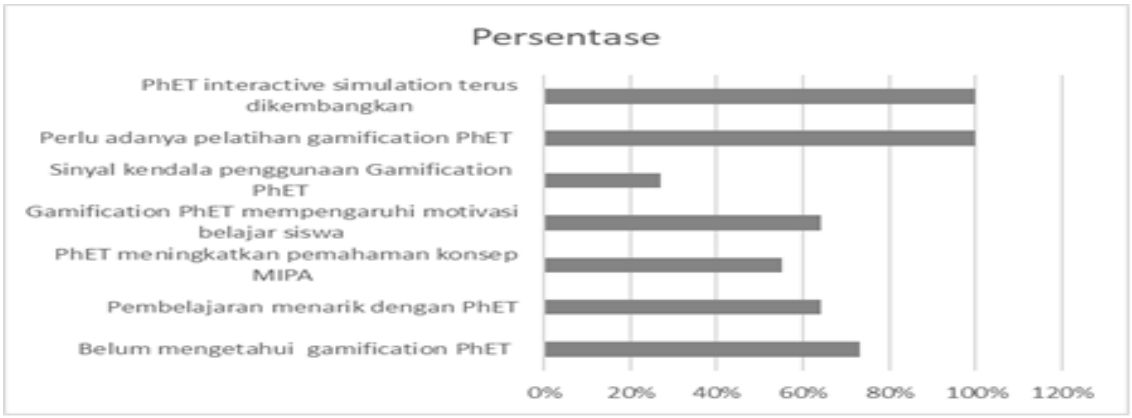


Diagram 1. Questionnaire Results

Based on data from observations, interviews, and initial questionnaires with teachers and students at Waskito High School, several key issues were identified, including: low student interest and motivation in science lessons. This low interest and motivation are due to monotonous and less interactive learning methods. Learning is still dominated by lectures and practice exercises, without adequate visual media or simulation support. Teachers have not fully integrated technology into science lessons, either due to limited knowledge or a lack of technical training.

Abstract concepts in science are difficult for students to grasp due to the lack of supporting visualizations or direct experiments. There is no systematic gamification approach to learning activities that can increase student engagement. The lack of variety in learning media means that students' diverse learning needs are not fully met. Learning evaluation remains cognitive in nature and does not address aspects of science process skills or collaborative learning.

B. Discussions

Learning at Waskito High School is dominated by lectures, with little use of visual media and simulations. This makes learning monotonous and less interactive. This community service activity aims to provide training to Waskito High School teachers on PhET Interactive Simulation gamification as a learning innovation. Based on questionnaire results, 73% of science and natural science teachers are unfamiliar with or do not yet use PhET Interactive Simulation media in their learning. 100% of teachers who completed the questionnaire require training on PhET Simulation gamification. Children are now familiar with games, and they use their mobile phones for entertainment, among other things. One way to increase children's learning motivation is by incorporating games into the learning process. The gamification learning model is currently developing. Gamification is a game-based learning concept (Dhenisha & Sarah, 2022). The main focus of gamification learning is to motivate students to access/learn learning materials and engage them in the learning process through rewards for student achievement (Ariani, Diana, et al., 2020).

Gamification can be optimally implemented by utilizing advances in technology and information as a learning medium, one of which is PhET Interactive Simulation. The results of the questionnaire showed that 64% of the PhET Simulation gamification was interesting and could motivate students in learning mathematics and natural sciences. Physics Education and Technology (PhET) is a simulation media developed by Katherin Perkins et al. from the University of Colorado, United States. This PhET simulation is made in Java or Flash format so it can be used directly from the website using a standard web browser (Rizaldi, D. R. et.al. 2020). The fields of study in PhET interactive simulation include mathematics, physics, chemistry, biology, and earth science. PhET interactive simulation contains simulations and games that can make it easier for students to understand the concept of a material. PhET interactive simulation is very helpful in modeling abstract materials (Rizaldi, D. R. et.al. 2020).

Table 1. Comparison of Before and After Research

Indicators	Before	After
Understanding PhET	27%	100%
Using PhET	27%	91%
Understanding Gamification	36%	100%
Preparing PhET-Based Lesson Plans	9%	82%
Ready to Implement	18%	91%

The IPTEKS transfer activity in the form of training and mentoring for the implementation of Gamification and PhET Interactive Simulation to MIPA teachers at SMA Waskito Tangerang Selatan has produced several achievements as follows: (1) Increased competency of MIPA teachers in the use of learning technology. (2) MIPA teachers showed a significant increase in understanding and skills in using PhET Simulation as a learning medium, they were able to operate interactive simulations according to the material topic, as well as modify learning to be more interesting and contextual. (3) Mastery of gamification strategies in learning where teachers have understood and applied gamification elements in the learning process, such as giving points, challenges, leaderboards, and rewards, which have been proven to increase student participation and learning motivation. (4) Innovative RPP products based on gamification and PhET which are compiled and implemented at least 3 innovative RPPs from the subjects of Physics, Chemistry, and Biology, which integrate PhET simulations and gamification strategies.

These RPPs have been tested in class and received positive responses from students. (5) Increased enthusiasm and understanding of students in the MIPA material, based on the results of interviews and questionnaires with students shows that this approach makes learning feel more fun and easier to understand. Most students feel more interested and active in participating in learning activities. (6) The formation of a creative MIPA teacher community at school, this activity also encourages the formation of a MIPA teacher working group (pokja) at Waskito High School which focuses on developing media and learning methods based on technology and digital innovation.

CONCLUSION

The conclusion of the study, "Gamification of PhET Interactive Simulations as an Innovation in Mathematics and Natural Sciences Learning at SMA Waskito, South Tangerang," successfully demonstrated that the implementation of gamification in PhET interactive simulations is an effective strategy in addressing the lack of learning innovation and low student motivation in mathematics and natural science subjects.

The analysis and discussion revealed teachers' enthusiasm for implementing PhET-based learning, suggesting it could be a solution for increasing student engagement, conceptual understanding, and enthusiasm for learning. The essence of this finding is that the combination of PhET's rich interactive visualizations with motivating gamification elements (such as challenges, points, and instant feedback) can create a more dynamic, relevant, and enjoyable learning environment.

This innovation is not merely a teaching tool, but a new paradigm with the potential to revolutionize the way students at SMA Waskito, and even other schools, approach and master mathematics material often considered difficult and boring.

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