Pedagogical Research
2024, 9(4), em0221
e-ISSN: 2468-4929
https://www.pedagogicalresearch.com

MODESTUM

Research Article

OPEN ACCESS

Physics education technology (PhET) as a game-based learning tool: A quasi-experimental study

Ogi Danika Pranata [1]*

[1] Department of Physics Education, IAIN Kerinci, Sungai Penuh City, Jambi, INDONESIA
***Corresponding Author:** ogidanika@gmail.com

Citation: Pranata, O. D. (2024). Physics education technology (PhET) as a game-based learning tool: A quasi-experimental study. *Pedagogical Research, 9*(4), em0221. https://doi.org/10.29333/pr/15154

ARTICLE INFO

Received: 01 Jun. 2024

Accepted: 08 Sep. 2024

ABSTRACT

Game-based learning has emerged as a promising approach to enhance students' engagement and understanding in educational settings. This study investigates the effectiveness of integrating physics education technology (PhET) simulations as game-based learning tools in teaching physics concepts related tao equilibrium system. A quasi-experimental design was employed, comparing the performance of students exposed to PhET simulations (experimental group) with those taught through traditional methods (control group). Results indicate significant improvements in both understanding and motivation among students in the experimental group, particularly in solving complex physics problems. Furthermore, students perceived PhET simulations positively, emphasizing their value in enhancing learning experiences. The findings underscore the potential of game-based learning tools like PhET simulations in promoting active learning and conceptual understanding in physics education. Future research directions include exploring long-term effects, conducting comparative studies across diverse educational contexts, and investigating the impact on various learning outcomes to further validate the efficacy of game-based learning approaches.

Keywords: balancing act, game-based learning, PhET simulation, physics, quasi-experimental

INTRODUCTION

One of the significant challenges in education, particularly in mathematics and science learning within schools, is enhancing student engagement in innovative exploratory activities and integrating technology into the learning process (Whitacre et al., 2019). The challenge becomes increasingly formidable with the rapid advancements in science and technology (OECD, 2018). This challenge has, in fact, been present since the emergence of computers in the 1980s. A question posed by Redish (1993), "Are computers appropriate for teaching physics?", directed scientists and educators to incorporate computers into physics education at various levels.

The importance of integrating technology into science education, particularly physics, cannot be overstated. Physics has a close relationship with technological advancements. Numerous technologies have evolved based on physics principles, such as the internet and Wi-Fi, mobile phones, cameras, solar panels, and many other everyday technologies (Winter & Hardman, 2020). Subsequently, these technologies are reused to deepen the understanding of physics and in physics education in schools (Winter & Hardman, 2020). This process creates a cycle between physics and technology. Therefore, there have been numerous computer applications in education since the late 20th century, which continue to evolve to this day.

In the 21st century, an online platform has emerged in the form of technology-based simulations that provide open access to all, especially educators and students. These simulations are known as physics education technology (PhET) (Wieman & Perkins, 2006). Previous studies have revealed that PhET simulations have developed into effective and beneficial tools for learning at various school levels (Wieman & Perkins, 2006; Wieman et al., 2010), especially in secondary schools (Perkins et al., 2012; Wieman et al., 2010). PhET simulations have also proven effective even during the pandemic (Perkins, 2020). PhET can be utilized as an aid or tool in online and blended learning (Pranata & Seprianto, 2023). Thus, on one hand, the pandemic seems to only have a negative impact on education, such as triggering boredom in learning (Putri & Pranata, 2023). But on the other hand, the pandemic has made us realize the need to engage and educate the next generation in science and math (Perkins, 2020). In various conditions, PhET simulations can still be utilized with varied learning activities (Rehn et al., 2013).

Varied learning activities are fundamentally beneficial for students, especially in enhancing their engagement in the learning process and learning motivation (Cahyani & Pranata, 2023; Hampden-Thompson & Bennett, 2013). Previous studies also suggest exploring the use or integration of technology in learning (Cahyani & Pranata, 2023). From the perspective of integrating technology into learning, technology-based or computer-based activities are essentially divided into two categories: constructive

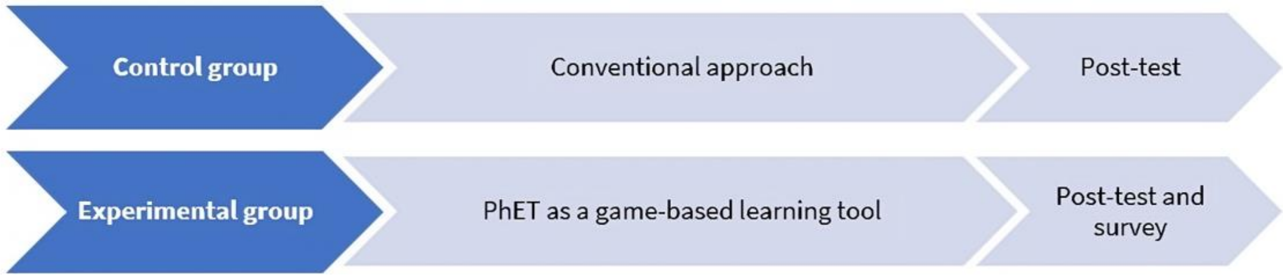


Figure 1. Research design (Source: Author's own elaboration)

learning and learning based on game (Redish, 1993). PhET simulations possess both of these features. Constructively, PhET simulations can serve as tools for students to explore phenomena and understand concepts through various features available in the simulations (Pranata, 2023a, 2024) and act as confirmation tools for students when answering questions (Pranata, 2023c, 2024). PhET simulations are also developed with animated, interactive, and game-like environments (Wieman & Perkins, 2006). Most PhET simulations feature games or play elements. This feature is called built-in games (Perkins et al., 2012). One example is the simulation for the equilibrium system (balancing act simulation).

The presence of game features can be applied to learning processes and evaluation. Essentially, games in learning can be digital or non-digital. Built-in games in PhET simulations are designed as simple as possible but can create productive and engaging learning opportunities for students (Perkins et al., 2012). The games–while relatively simple–are designed to target the development of core concepts and learning goals and to enable users to test and revise their understanding (Johnson-Glenberg et al., 2014). Such learning conditions are referred to as game-based learning.

The use of games in learning has been demonstrated as a useful learning tool and as an activity to promote social skills (Cardinot & Fairfield, 2019). Game-based learning also creates a more motivating and engaging learning experience (Ke et al., 2016; Nadolny et al., 2020; Plass et al., 2015; Pranata, 2023b; Qian & Clark, 2016; Zeng et al., 2020) and provides opportunities to develop valued 21st century skills (e.g., collaboration, creativity, communication, critical thinking) (Qian & Clark, 2016). Previous studies indicate that students in game-based learning groups (digital and non-digital) performed significantly better in content knowledge assessment and had higher self-efficacy than the traditional lecture group (Wang & Zheng, 2021). Other studies also confirm that students in the game-based learning group performed better than the educational video group and the traditional group (Zeng et al., 2020).

Based on the foregoing explanations, it can be concluded that the implementation of PhET simulations in learning has proven to be beneficial. Furthermore, PhET simulations are also available in games. Previous explanations have also confirmed that game-based learning offers many benefits. The combination of both (PhET simulations and game-based learning) is predicted to offer additional advantages in learning, particularly in physics. However, testing is still required to determine whether the combination is truly effective and beneficial for implementation in physics education. Therefore, this research aims to address the following question: Does PhET simulations as game-based learning tools improve student learning outcomes in physics compared to traditional methods? By investigating this, we can assess the effectiveness of combining these innovative approaches in enhancing physics education.

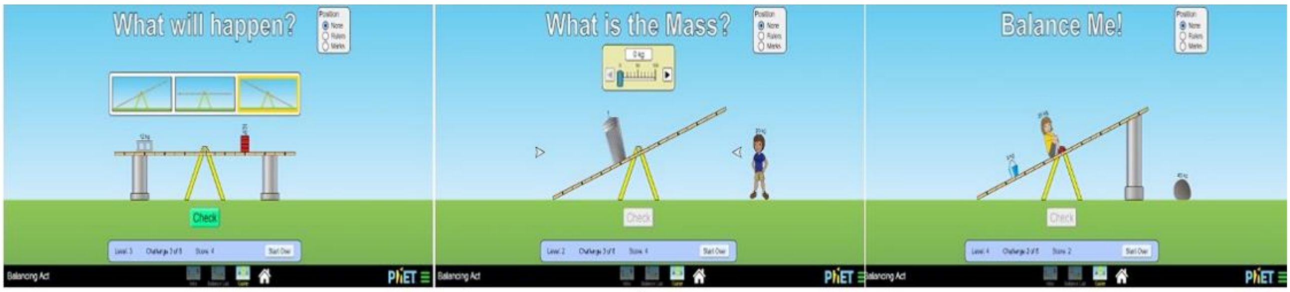
Ultimately, we should share the same view as Redish regarding the question he posed. Computers (technology) can assist students in learning physics, but with various considerations such as curriculum and student conditions. Therefore, besides conducting experimental studies comparing learning using PhET simulations as a game-based learning tool, students' perceptions of such learning should also be gathered. Understanding students' perceptions of science (especially physics) and technology is important because it can influence students' future development (Putri et al., 2024).

MATERIALS AND METHODS

A quasi-experiment with a post-test only design was employed as the research method. This design, illustrated in **Figure 1**, was chosen to measure the impact of game-based learning with PhET simulations on student learning outcomes. The quasi-experimental approach was structured due to the inability to randomly assign students to groups, a common limitation in real-world educational settings. This design allows for controlled testing of the hypothesis that game-based learning with PhET simulations enhances learning outcomes more effectively than traditional methods.

The study involved two classes of junior high school students in grade 7 from a school in Kerinci Regency. Each class consisted of 20 students. These classes were divided into an experimental class and a control class. The experimental class received instruction using PhET simulations in a game-based learning environment, specifically through the "balancing act" simulation (https://phet.colorado.edu/en/simulations/balancing-act), which explores the balance system of objects using a seesaw. In contrast, the control class received conventional instruction through teacher explanations and classroom discussions on the same topic. The post-test was administered to both groups to assess their understanding, while students in the experimental class also participated in a brief survey regarding their experience with PhET as a game-based learning tool.

The post-test consisted of 24 questions divided into 4 difficulty levels (level 1-level 4), with 6 questions for each level. The questions were also classified into three groups based on their types, with 2 questions representing each group at each level. Type



a b c

Figure 2. Example question types: (a) type A, (b) type B, and (c) type C (https://phet.colorado.edu/en/simulations/balancing-act)

Table 1. Student's understanding level

Average score ($\bar{x}$)	Level
$90 \leq \bar{x} \leq 100$	Advanced
$80 \leq \bar{x} < 90$	Proficient
$70 \leq \bar{x} < 80$	Basic
$\bar{x} < 70$	Below basic*

Note.*Does not meet minimum criteria

Table 2. Descriptive statistic I: Both groups

Data	N	Min	Max	Mean		Standard deviation	Skewness	
				Statistic	Standard error		Statistic	Standard error
Control group	17	25.00	100.00	59.56	5.51	22.71	0.18	0.55
Experimental group	18	29.17	100.00	80.56	5.06	21.48	-1.37*	0.54

Note. *The data is not normally distributed

A questions ("What will happen?") aimed to assess whether students understood the state of the system, whether balanced or unbalanced. When unbalanced, students were also asked to determine the tendency of the seesaw system to rotate, either clockwise or counterclockwise. An example of a type A question is shown in part a in **Figure 2**. Then, type B questions aimed to assess whether students could create a balanced system, where one or two objects were already on one side of the seesaw, and students placed other objects to balance it. An example of a type B question ("Balance me!") is shown in part b in **Figure 2**. Finally, type C questions ("What is the mass?") aimed to determine the mass of the objects in the balanced system. Before calculating the mass, students had to first create a balanced system to facilitate the calculation. An example of a type C question is shown in part c in **Figure 2**.

Subsequently, student understanding data based on the post-test answers were collected and analyzed. Data analysis began with descriptive statistics to understand the overall understanding of the concept of balance from various perspectives. First, the general understanding of students based on different groups (experimental and control) was examined. Second, student understanding could also be assessed from an individual student perspective. Third, the distribution of student understanding data was also shown based on the difficulty level of questions and question types. Students were classified into three groups based on their understanding scores, divided by a standard minimum criterion for science subjects, which is 70. The rules for classifying student understanding are shown in **Table 1**.

The results of descriptive statistical analysis could then serve as the basis for further testing, namely comparing the experimental and control class data using independent samples t-test or Mann-Whitney U test. Those test was processed using the SPSS statistical application.

RESULTS AND DISCUSSION

Descriptive Statistic and Checking Assumptions

The analysis of the post-test questions regarding the balance system was conducted descriptively for the students overall and based on different student groups (control and experimental). However, some students did not take the post-test, so they were not included in the analysis. The results of the descriptive statistical analysis are shown in **Table 2**.

The descriptive statistical analysis results indicate a difference in mean scores between students from different groups. Students from the experimental group (80.56) had a higher mean score compared to students from the control group (59.56). This suggests that *students who participated in game-based learning using PhET simulations had higher post-test scores, or better conceptual understanding compared to students who underwent conventional instruction through teacher explanations and classroom discussions*.

The advantage of implementing PhET simulations as a game-based learning tool in the experimental class was further confirmed based on the distribution of student understanding levels for each group (control and experimental), as shown in **Figure 3**. Each student's post-test score was categorized according to the understanding level classification outlined in **Table 1**.

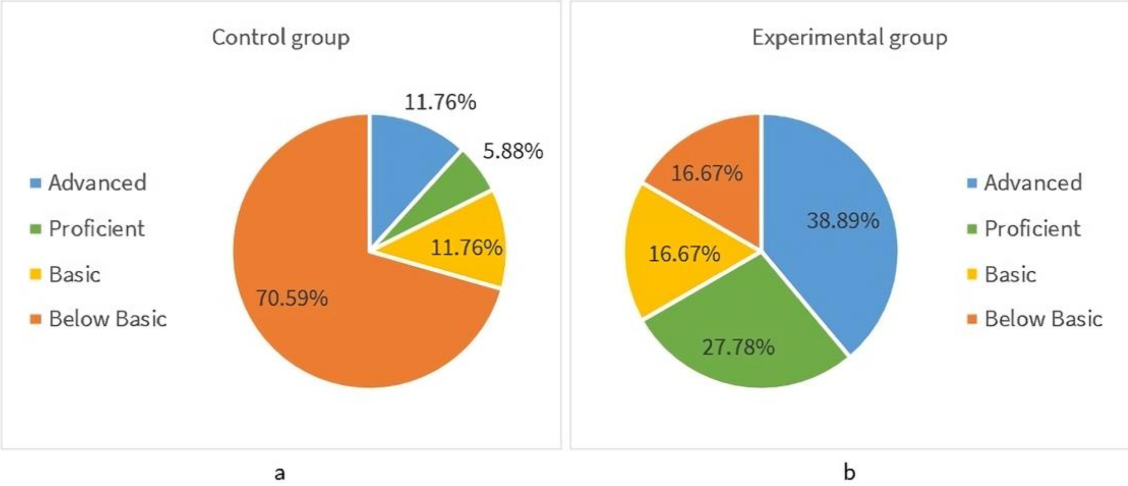


Figure 3. Students' understanding level: (a) control group and (b) experimental group (Source: Author's own elaboration)

Table 3. Descriptive statistic II: Group-question types

Group-question types	N	Min	Max	Mean		Standard deviation	Skewness	
				Statistic	Standard error		Statistic	Standard error
Control-A	17	50.00	100.00	78.68	4.26	17.55	-0.13	0.55
Control-B	17	0.00	100.00	53.68	6.32	26.06	-0.26	0.55
Control-C	17	0.00	100.00	46.32	7.93	32.71	0.22	0.55
Exp-A	18	37.50	100.00	84.03	4.93	20.92	-1.54*	0.54
Exp-B	18	37.50	100.00	79.17	5.15	21.86	-0.73	0.54
Exp-C	18	12.50	100.00	78.47	6.99	29.64	-1.30*	0.54

Note. *The data is not normally distributed

Part a in **Figure 3** indicates that less than one-third of the students from the control group (29.41%) met the minimum criteria. Only 17.64% of students demonstrated proficient or advanced understanding. The understanding level of students from the control group was predominantly below basic or did not meet the minimum criteria (> 70), accounting for 70.59% of the total students. Better student understanding distributions were found for the experimental class, as shown in part b in **Figure 3**. Five out of six students (83.33%) in the experimental class exceeded the minimum criteria. Approximately 66.67% of students demonstrated proficient and advanced understanding. The below-basic understanding level was approximately 16.67%.

Based on the descriptive statistical analysis results in **Table 2** and the distribution of student understanding as shown in **Figure 3**, it can be concluded that student understanding of the balance system was found to be better when learning was conducted through game-based learning using PhET simulations. In other words, game-based learning using PhET can support students' conceptual understanding. Other studies have also revealed similar findings regarding PhET simulations' support for students' acquisition and understanding of physics concepts, such as vector, projectile motion (through "vector addition" and "projectile motion" simulation) (Pranata & Seprianto, 2023), gravity ("gravity and orbits" simulation) (Pranata, 2023a), conservation of energy ("energy skate park" simulation) (Paul et al., 2013), reflection and refraction ("bending light" simulation) (Podolefsky et al., 2013), and more advanced concepts such as quantum phenomena (McKagan et al., 2008). Other studies have shown similar findings for understanding chemical concepts like molecular structure (the "build a molecule" simulation) (Rehn et al., 2013).

Next, descriptive analysis was conducted for the comparison of student groups based on question type (A, B, and C). The results are presented in **Table 3**.

The descriptive statistical analysis results in **Table 3**, particularly the mean values, indicate that type A questions were better understood by students from both groups. The average scores were 78.68 and 84.03 for the control and experimental groups, respectively. Both average scores surpassed the minimum criteria. Lower understanding was observed for type B questions and even lower for type C questions.

Interestingly, significant differences for each question type were found among students in the control group. Only type A questions exceeded the minimum threshold (70). Type B and type C questions had much lower scores, 53.68 and 46.32, respectively. In comparison, much smaller differences were found in the mean scores for each question type among the experimental group. Furthermore, students in the experimental class had average scores exceeding 70 for all three question types. Analysis based on question type also confirmed that students in the experimental class participating in game-based learning using PhET had higher understanding compared to students in the control class. Visually, the average scores for each group based on question type are shown in **Figure 4**.

Subsequently, descriptive analysis was also conducted for the comparison of student groups based on the difficulty level of questions (level 1-level 4). The results are shown in **Table 4**.

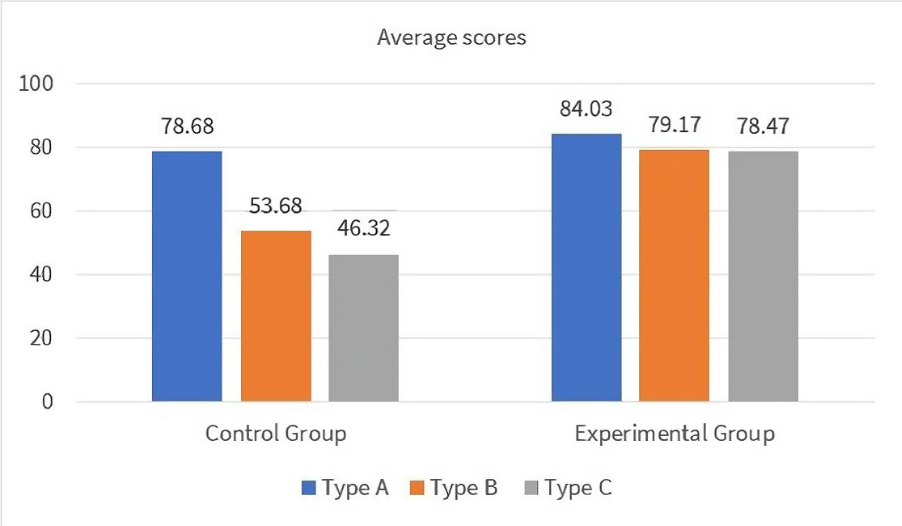


Figure 4. The average scores based on question types (Source: Author's own elaboration)

Table 4. Descriptive statistic III: Group-question levels

Group-question levels	N	Min	Max	Mean		Standard deviation	Skewness	
				Statistic	Standard error		Statistic	Standard error
Control-level 1	17	0.00	100.00	66.67	7.00	28.87	-0.98	0.55
Control-level 2	17	16.67	100.00	74.51	5.74	23.66	-0.82	0.55
Control-level 3	17	0.00	100.00	50.98	7.07	29.15	0.22	0.55
Control-level 4	17	0.00	100.00	46.09	7.08	29.18	-0.07	0.55
Exp-level 1	18	50.00	100.00	88.89	3.56	15.12	-1.30*	0.54
Exp-level 2	18	33.33	100.00	79.63	4.77	20.26	-0.85	0.54
Exp-level 3	18	16.67	100.00	81.48	6.99	29.64	-1.51*	0.54
Exp-level 4	18	0.00	100.00	72.22	6.74	28.58	-1.06*	0.54

Note. *The data is not normally distributed

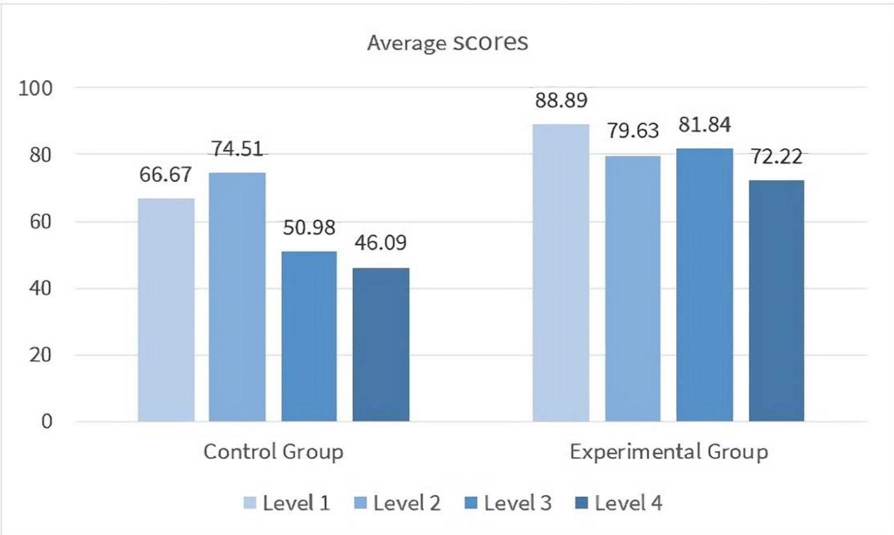


Figure 5. The average scores based on question levels (Source: Author's own elaboration)

Logically, as problems become more difficult (levels increase), students tend to score lower. Based on the mean values in **Table 4**, several interesting findings can be concluded. These findings are more easily observed when mean data are presented using diagrams (**Figure 5**).

Firstly, the data patterns were not as predicted in both classes. Student scores did not decrease linearly with increasing question difficulty. The control class started with an increase in scores, then gradually decreased. Meanwhile, the experimental class started with a decrease, slightly increased, and then decreased again. Secondly, the highest scores in the experimental class were as predicted, but the highest scores in the control class were not as predicted. It makes sense to think that students would have higher scores when faced with lower difficulty questions (level 1). The experimental class had the highest scores at level 1. However, the control class had high scores at level 2. Thirdly, overall, it can be concluded that there were differences in scores between the experimental and control classes for each level, with varying differences.

Table 5. Mann-Whitney U test I: Average scores

	Average scores
Mann-Whitney U	74.500
Wilcoxon W	227.500
Z	-2.601
Asymptotic sig. (2-tailed)	0.009

Table 6. Mann-Whitney U test II: Group-question types

	Type A	Type B	Type C
Mann-Whitney U	119.000	69.500	69.000
Wilcoxon W	272.000	222.500	222.000
Z	-1.159	-2.794	-2.827
Asymptotic sig. (2-tailed)	0.246	0.005*	0.005*

Table 7. Mann-Whitney U test III: Group-question levels

	Level 1	Level 2	Level 3	Level 4
Mann-Whitney U	75.500	135.000	69.000	76.000
Wilcoxon W	228.500	288.000	222.000	229.000
Z	-2.666	-0.614	-2.859	-2.580
Asymptotic sig. (2-tailed)	0.008*	0.539	0.004*	0.010*

Although differences in mean scores were found between the control and experimental group students from various perspectives (overall, question types, and difficulty levels), these differences could not be concluded as significant. Further testing is required, namely independent samples t-test or Mann-Whitney U test. One assumption that must be met to use an independent samples t-test is that the data are normally distributed for each group of data to be compared. Data distribution can be determined based on the values in the skewness statistic column (**Table 2**, **Table 3**, and **Table 4**). Data distribution is considered normal when the skewness statistic value is not less than -1 and not greater than +1 (Leech et al., 2005; Morgan et al., 2004). If the data are not normally distributed, then the appropriate test is the Mann-Whitney U test. The analysis of the skewness statistic column in **Table 2**, **Table 3**, and **Table 4** indicates that some data groups are not normally distributed, as indicated by the asterisks (*). Thus, the comparison test between the two groups is processed using the Mann-Whitney U test.

Comparative Test: Mann-Whitney U Test

The results of the comparative test of scores between the two groups overall, based on question type, and question level using the Mann-Whitney U test are presented in **Table 5**, **Table 6**, and **Table 7**.

Table 5 indicates a significance value of 0.009, which is less than 0.05, suggesting a significant difference in students' understanding of the concept of equilibrium between the experimental and control classes. This finding is consistent with the objective of PhET simulations, which aim to facilitate student learning through interactive animations resembling games, thereby promoting exploration (Wieman & Perkins, 2006) and adherence to scientific methods in lab and inquiry activities (Pranata, 2023a; Wieman et al., 2010). Moreover, previous studies have shown that PhET simulations can be as productive as real equipment when properly designed and applied in appropriate contexts (Finkelstein et al., 2005; Keller et al., 2006).

Additionally, the inclusion of game-like features in PhET simulations encourages student interaction with the challenges presented (Rehn et al., 2013), fostering engagement in scientific and mathematical practices (Johnson-Glenberg et al., 2014; Perkins, 2020), increasing classroom discussion, stimulating student questions (Perkins et al., 2012), and support student sense-making of core concepts (Johnson-Glenberg et al., 2014). Furthermore, game-based learning also plays a role in enhancing learning motivation, activity, willingness to express opinions, and understanding of the concepts (Pranata, 2023b).

Some studies refer to it by a different term, namely "play featured" (Podolefsky et al., 2013; Whitacre et al., 2019). This feature supports student-centered learning (Podolefsky et al., 2013). Both game and play features are available in the design of several PhET simulations, including the "balancing act" simulation applied in the experimental class. These available features are referred to as design-in features. Design-in features in PhET simulations implicitly guide students to explore pedagogically useful paths without explicitly directing them. Previous studies have demonstrated that implicit scaffolding enables students to have more control over their learning trajectory and engage in authentic scientific process skills, while also facilitating productive content learning (Paul et al., 2013; Pranata, 2023a). Furthermore, these design-in features in PhET simulations provide a unique tool that enhances learning enjoyment and effectiveness (Wieman et al., 2010).

Further comparison between the two groups is shown based on the type and level of questions. The comparison results through the Mann-Whitney test based on question types and levels are summarized in **Table 6** and **Table 7**.

Based on the type of questions (**Table 6**), significant differences were found between students from the experimental and control classes in type B and type C questions. Both types of questions had a significance value of 0.005 ($p < 0.05$). In other words, no significant difference was found in type A questions ($p > 0.05$).

Essentially, game-based learning has been proven to provide many benefits. Previous studies have revealed that game-based learning helps students in learning, understanding the material, and improving mathematical skills (Pranata, 2023b). These findings are consistent with the case of balance, which requires simple mathematical skills for all three types of questions, determining the system's condition, producing two balanced conditions, and determining mass values.

These findings are reasonable based on the explanations provided for each question type, as detailed in the method section. Question type A ("What will happen?") only requires students to select one of three available answers, whether the system is in balance, rotating clockwise, or counterclockwise, as shown in part a in **Figure 2**. Students only need to perform simple calculations to understand the effect of mass and distance from the pivot point on both sides of the balance board. If the mass and distance calculations on both sides are equal, then the system can be concluded to be in balance. This is the simplest calculation among the three question types. Under these conditions, students from both the control and experimental classes have high scores, with respective averages of 78.68 and 84.03, as shown in **Table 3** and **Figure 4**. Although the experimental class has a higher score with a difference of 5.35 on a scale of 100, this difference was found to be not significant.

Significant differences were found for more complex problems involving slightly more difficult calculations, namely question type B ("Balance me!") and C ("What is the mass?"), as shown in part b and part c in **Figure 2**. Question type B has 8 answer options to place objects aiming to achieve a balanced system. Furthermore, question type C requires two steps of resolution (balancing the system and calculating mass) and has broader answer options, ranging from 0 to 100 kg. A large difference in scores between the experimental and control classes was found for both question types, namely 25.49 on a scale of 100 for question type B and 32.15 on a scale of 100 for question type C. This difference or gap in scores was previously illustrated in **Figure 4**.

Furthermore, based on the question level (**Table 7**), significant differences were found between students from the experimental and control classes in all question levels, except for level 2 because its significance value was greater than 0.05 ($p = 0.539$). The significance values for levels 1, 3, and 4 were found to be less than 0.05. These findings align with interesting conclusions as previously revealed in the descriptive results section for different question levels, as shown in **Table 4** and **Figure 5**.

The game features in PhET simulations support learning processes focused on students' ideas and learning content (Podolefsky et al., 2013). Assuming the same initial abilities of students, learning using PhET as a game-based learning tool as a special treatment (experimental class) did not provide significant differences for easy question types or problems like in type A questions. Even without treatment (control class), most students were still able to answer type A questions correctly. The treatment showed differences when solving slightly more complex problems like in type B and type C questions.

Based on this framework, one would expect a similar pattern for question levels, with no differences observed for easier levels (1 and 2) and differences found for more challenging levels (3 and 4). However, an anomaly was observed in the data for level 1, where significant differences were also found. Further investigation revealed that some students from the control group faced difficulties with type B and type C questions from level 1, contributing to the significant difference observed. Additional research is warranted to confirm or refine the findings of this study. Nevertheless, this study meticulously identified the details of questions, as well as the difficulties and misconceptions experienced by students in the learning process, as summarized in **Table 8**.

Table 8. Questions explanation, students' difficulties, and misconceptions

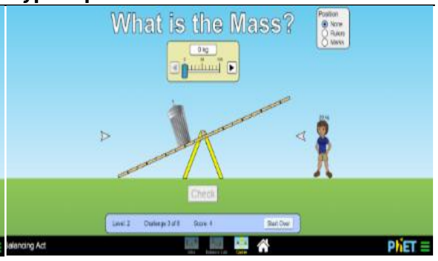
Type A question	Type B question	Type C question
		
Mathematical formulation: plug and chug: $m_1 \times r_1 = m_2 \times r_2$ All variables are known from the picture/simulation. In type A problems, students only need to input the value of each variable and determine whether the values are equal or not. Equal values indicate a balanced state, and vice versa. If the left side (index 1) is larger, then the system will lean to the left (rotate counterclockwise), and vice versa.	**Mathematical formulation: one variable missing: $m_1 \times r_1 = m_2 \times r_2$** All variables are known, except r_2 (the distance of the object from the center). In type B problems, students can solve it by inputting three values into the equation (m_1, r_1, and m_2) pada persamaan. Then, they determine the value of r_2 which represents how far the object (m_2) will be placed from the pivot point to achieve a balanced state. There are 8 options for the value of r_2 available as answer choices.	**Mathematical formulation: two variables missing: $m_1 \times r_1 = m_2 \times r_2$** There are two variables that are unknown, namely m_1 and r_2. In type C problems, there are two stages of solving. First, placing the right mass (m_2) on the balance system or board to achieve equilibrium. Once the equilibrium state is found or the value of r_2 is known, the problem becomes identical to type B. However, the calculation is to determine the left mass (m_1).
Students' difficulties and misconceptions 1. Mass and distance considerations: • When one object on the left and one on the right with the same distance but different masses, it should result in an unbalanced system, yet some students perceive it as balanced.	**Students' difficulties and misconceptions** 1. Observation skills: Issues related to precision (mass and distance) were also found for type B problems. 2. Simple calculations: Students not only lack precision in determining the values of known variables in the simulation but also in calculating the distance of the object (r_2).	**Students' difficulties and misconceptions** 1. Observation skills: Precision issues are still present but with a lower frequency. This is because in the first stage of type C problems, students are directed to interact with the system to achieve equilibrium. As a result, students become more observant of mass 2 (m_2) and the distance of object 1 (r_1), which is manipulated by the students.

Table 8 (Continued). Questions explanation, students' difficulties, and misconceptions

Type A question	Type B question	Type C question
• When placing one object with the same mass at slightly different distances, making them appear equidistant, students may perceive it as a balanced condition. 2. Simple calculations: Students may overlook simple multiplication in their calculations. 3. More complex calculations: • Students face difficulties when more objects are involved in the system. • As the level of the problem increases, involving more than two objects in the system, equations change accordingly: When one object is on the left and two on the right: $m_1 \times r_1 = (m_{21} \times r_{21}) + (m_{22} \times r_{22})$ When two objects are on the left and one on the right: $(m_1 \times r_1) + (m_{12} \times r_{12}) = (m_2 \times r_2)$ • Despite appearing more complex, the problem remains a plug-and-chug scenario	3. More complex calculations: • The same pattern is observed; as problems become more difficult, calculations involve equations with more variables. • This condition undoubtedly challenges students to determine r_2, such as in equations involving two objects on the left and determining r_2 for the object on the right using the equation: $(m_1 \times r_1) + (m_{12} \times r_{12}) = (m_2 \times r_2)$ • Even though all values are known except for r_2, some students struggle to solve it.	2. Complex calculations: Essentially, calculations revert to one variable again when the system is in equilibrium because r_2 is known, leaving only m_1 to be determined based on calculations. However, the calculations become more complex due to involving larger answer options (100 choices) compared to the previous types of problems, which were limited to 3 and 8 choices 3. More complex calculations: As the level increases, calculations also become more complex as they involve several masses in the system to be included in the calculations: $(m_1 \times r_1) + (m_{12} \times r_{12}) = (m_2 \times r_2)$. Although using the same equations, calculations become more complex due to the same reason (involving large numbers).

Table 9. Descriptive statistic IV: Students' perception

Data	N	Min	Max	Mean		Standard deviation	Skewness	
				Statistic	Standard error		Statistic	Standard error
Student's perception	18	63.33	100.00	83.89	2.50	10.62	-0.01	0.54

Table 10. Distribution of students' response on perception

No	Students' perception (using PhET as a game based-learning tool in learning physics ...)	Score	Responses (student in %)				
			1	2	3	4	5
1	is interesting.	88.89	0.00	0.00	16.67	22.22	61.11
2	is motivating.	87.78	0.00	0.00	16.67	27.78	55.56
3	encourages active participation.	87.78	0.00	0.00	11.11	38.89	50.00
4	makes learning more interactive.	76.67	0.00	0.00	44.44	27.78	27.78
5	helps us in understanding.	85.56	0.00	0.00	11.11	50.00	38.89
6	is also useful for understanding other physics concepts.	76.67	0.00	11.11	22.22	38.89	27.78

Students' Perception

Perception of students towards game-based learning using PhET was only collected from the experimental class. Students' perceptions were also presented in the form of descriptive statistical analysis (**Table 9**) and the distribution of student responses for each perception statement (**Table 10**).

Overall, students' perception towards PhET as a game-based learning tool in learning physics is relatively high, with an average score of 83.89 and a standard deviation of 10.62. The analysis of each perception statement showed that the highest score was 88.89%, representing the view that PhET simulations as a game-based learning tool in learning physics are an engaging learning process. Previous experimental studies have revealed that learning through play is engaging and provides many benefits, such as enjoyment for students and highlighting the importance of the learning process (Podolefsky et al., 2013). However, it's important to note that learning through play or game-based learning does not automatically guarantee effective learning. Teachers play a crucial role in determining the activities that will be introduced and facilitated to support and create effective learning in achieving planned learning objectives (Cahyani & Pranata, 2023). To maximize the impact of simulation in game-based learning, previous studies have suggested implementing free play or open play before discussing the simulation (Perkins et al., 2012; Podolefsky et al., 2013).

One of the main factors that make game-based learning attractive is the element of competition in games (Huizenga et al., 2017). Competition can be designed by teachers based on the content, simulation, and game to be applied. It can take the form of scores in the game or progress in completing the game. Furthermore, previous studies also suggest the importance of determining learning outcomes as a basis for developing learning activities that integrate game characteristics (Cardinot & Fairfield, 2019; Nadolny et al., 2020). This can create a more engaging learning experience and promote active participation, interaction, interest, and motivation.

Furthermore, motivation and active participation of students in game-based learning are perceived as the second highest aspect, with a score of 87.78%. The promise of using games for learning lies in the cohesive engagement of play and learning to compose a highly motivated learning experience (Ke et al., 2016). Motivational effects of games exist because students can experience the value of connecting theory and practice, requiring them to apply what they learned in class to successfully play the game and make what they had previously learned meaningful (Huizenga et al., 2017). Previous studies have also confirmed that computer educational games impact academic achievement motivation (Partovi & Razavi, 2019). The motivation provided by games is considered the most important feature regarding their potential for learning. However, it's also important to note that games are able to facilitate learning engagement on cognitive, affective, and sociocultural levels that promote learning in ways other media cannot (Plass et al., 2015).

Previous studies have highlighted the positive aspects of game-based learning, emphasizing the prompts and interactive characteristics of the game-based learning environment (Zeng et al., 2020). In game-based learning, students are actively engaged, receive feedback on their actions, and benefit from visual representations of processes (Huizenga et al., 2017). This engagement is an integrated and continuous process that evolves from affective engagement driven by optimal challenge to cognitive engagement grounded in playfulness, and potentially culminates in game-action-based content engagement (Ke et al., 2016).

The PhET simulations have been proven to support students' understanding of concepts related to the simulation content, including abstract and complex topics. Comparative testing between the experimental and control groups showed significant differences in questions or content that were more complex. The views of students from the experimental group also align with these findings, as they agree that PhET simulations as game-based learning tools can help them understand the material. The built-in design of PhET simulations, such as visualization, interactivity, context, and effective computational use, has been particularly effective in assisting students in understanding abstract and counterintuitive concepts (McKagan et al., 2008).

These findings are consistent with a review of 172 articles, indicating that most digital games are used to enhance scientific knowledge and concept learning, while less than one-third focus on improving students' problem-solving skills. Moreover, only a few studies have explored outcomes related to scientific processes, affect, engagement, and socio-contextual learning (Li & Tsai, 2013). Additionally, related studies have highlighted that game-based learning creates an environment where game content and gameplay contribute to the acquisition of knowledge and skills. Game activities often involve problem-solving scenarios and challenges, which offer players a sense of achievement (Qian & Clark, 2016). Using games in teaching can provide an authentic context by simulating real-life situations, thereby facilitating meaningful learning experiences (Huizenga et al., 2017).

In fact, the application of PhET simulations as a game-based learning tool not only benefits students but also supports and enhances the quality of teaching and aligns with the integration of technology into the curriculum (Wieman et al., 2010). It's important to emphasize that PhET simulations do not replace the role of teachers. Their implementation in education still relies on teacher guidance. Therefore, it's crucial to determine the level of involvement and guidance from teachers. Previous studies have shown that minimal guidance is needed to promote optimal engaged exploration and conceptual understanding (Adams et al., 2008; Pranata, 2023a). This means that students are not left completely on their own to access and use PhET simulations; rather, teachers need to provide minimal guidance.

On one hand, the implementation of game-based learning in the context of education provides various benefits for both students and teachers. On the other hand, as found in previous studies, it indicates that on average, teachers do not intend to use video games in the near future (Bourgonjon et al., 2013). Therefore, game-based learning, whether digital or non-digital, should be introduced in teacher training programs.

CONCLUSIONS

In summary, the findings of this research underscore the potential of game-based learning, particularly when integrated with innovative educational technologies like PhET simulations, in enhancing students' learning experiences and outcomes in physics education. Different question types and levels demonstrated varying degrees of impact in distinguishing between experimental and control groups, with more complex questions showing greater differences. Game-based learning, facilitated by PhET simulations, showed promising results in improving students' engagement, motivation, and conceptual understanding. Students perceived PhET simulations as an effective and engaging learning tool, particularly in grasping abstract and complex concepts. While game-based learning offers substantial benefits, it is essential to emphasize the role of teachers in guiding students' exploration and conceptual understanding during the learning process.

Continued research and development efforts in this area are crucial for fostering effective teaching and learning practices in the digital age. In future research, it is essential to delve into several key areas. Firstly, investigating the long-term effects of game-based learning is crucial to ascertain the sustainability of improvements in students' understanding and motivation over an extended period. Additionally, developing and implementing teacher training programs can significantly enhance educators' familiarity with integrating game-based learning tools like PhET simulations into their teaching practices. Comparative studies across diverse educational contexts are necessary to evaluate the effectiveness of different game-based learning approaches and tools. Moreover, exploring the impact of game-based learning on various learning outcomes, such as problem-solving skills, critical thinking, and scientific processes, can provide valuable insights into its efficacy. Finally, understanding students' preferences and attitudes towards different game-based learning environments is essential for informing instructional design strategies and optimizing learning experiences.

Funding: No funding source is reported for this study.

Ethical statement: The author stated that the study did not require ethics committee approval. The study was conducted as part of an academic engagement which has gone through departmental scrutiny. Participants were informed about the study's objectives, procedures, potential risks, and benefits, and assured that their participation was voluntary, and they could withdraw at any time without negative consequences. The author further stated that the results of this study were used solely for educational research purposes and reported in a way that ensures participant anonymity, adhering to ethical standards in all dissemination of findings.

Declaration of interest: No conflict of interest is declared by the author.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the author.

REFERENCES

Adams, W. K., Paulson, A., & Wieman, C. E. (2008). What levels of guidance promote engaged exploration with interactive simulations? *AIP Conference Proceedings, 1064*, 59-62. https://doi.org/10.1063/1.3021273

Bourgonjon, J., De Grove, F., De Smet, C., Van Looy, J., Soetaert, R., & Valcke, M. (2013). Acceptance of game-based learning by secondary school teachers. *Computers and Education, 67*, 21-35. https://doi.org/10.1016/j.compedu.2013.02.010

Cahyani, V. D., & Pranata, O. D. (2023). Studi aktivitas belajar sains siswa di SMA Negeri 7 Kerinci [Study of students' science learning activities at SMA Negeri 7 Kerinci]. *Jurnal Pendidikan IPA, 13*(2), 137-148. https://doi.org/10.24929/lensa.v13i2

Cardinot, A., & Fairfield, J. A. (2019). Game-based learning to engage students with physics and astronomy using a board game. *International Journal of Game-Based Learning, 9*(1), 42-57. https://doi.org/10.4018/IJGBL.2019010104

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., Reid, S., & Lemaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Physics Education Research, 1*(1), Article 010103. https://doi.org/10.1103/PhysRevSTPER.1.010103

Hampden-Thompson, G., & Bennett, J. (2013). Science teaching and learning activities and students' engagement in science. *International Journal of Science Education, 35*(8), 1325-1343. https://doi.org/10.1080/09500693.2011.608093

Huizenga, J. C., ten Dam, G. T. M., Voogt, J. M., & Admiraal, W. F. (2017). Teacher perceptions of the value of game-based learning in secondary education. *Computers and Education, 110*, 105-115. https://doi.org/10.1016/j.compedu.2017.03.008

Johnson-Glenberg, M. C., Savio-Ramos, C., Perkins, K. K., Moore, E. B., Lindgren, R., Clark, D., Brady, C., Martinez-Garza, M., Adams, D., Killingsworth, S., Gaydos, M., Barany, A., & Holbert, N. (2014). Science sims and games: Best design practices and fave flops. In *Proceedings of the ICLS 2014* (pp. 1199-1208). https://doi.org/10.22318/icls2014.1199

Ke, F., Xie, K., & Xie, Y. (2016). Game-based learning engagement: A theory- and data-driven exploration. *British Journal of Educational Technology, 47*(6), 1183-1201. https://doi.org/10.1111/bjet.12314

Keller, C. J., Finkelstein, N. D., Perkins, K. K., & Pollock, S. J. (2006). Assessing the effectiveness of a computer simulation in conjunction with tutorials in introductory physics in undergraduate physics recitations. *AIP Conference Proceedings, 818*, 109-112. https://doi.org/10.1063/1.2177035

Leech, N. L., Barret, K. C., & Morgan, G. A. (2005). *SPSS for intermediate statistics. Use and interpretation*. Lawrence Erlbaum Associates. https://doi.org/10.4324/9781410611420

Li, M. C., & Tsai, C. C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology, 22*(6), 877-898. https://doi.org/10.1007/s10956-013-9436-x

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. E. (2008). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics, 76*(4), 406-417. https://doi.org/10.1119/1.2885199

Morgan, G. A., Leech, N. L., Gloeckner, G. W., & Barret, K. C. (2004). *SPSS for introductory statistics. Use and interpretation*. Lawrence Erlbaum Associates. https://doi.org/10.4324/9781410610539

Nadolny, L., Valai, A., Cherrez, N. J., Elrick, D., Lovett, A., & Nowatzke, M. (2020). Examining the characteristics of game-based learning: A content analysis and design framework. *Computers and Education, 156*, Article 103936. https://doi.org/10.1016/j.compedu.2020.103936

OECD. (2018). *The future of education and skills: Education 2030*. https://www.oecd.org/education/2030-project/

Partovi, T., & Razavi, M. R. (2019). The effect of game-based learning on academic achievement motivation of elementary school students. *Learning and Motivation, 68*, Article 101592. https://doi.org/10.1016/j.lmot.2019.101592

Paul, A., Podolefsky, N., & Perkins, K. (2013). Guiding without feeling guided: Implicit scaffolding through interactive simulation design. *AIP Conference Proceedings, 1513*, 302-305. https://doi.org/10.1063/1.4789712

Perkins, K. (2020). Transforming STEM learning at scale: PhET interactive simulations. *Childhood Education, 96*(4), 42-49. https://doi.org/10.1080/00094056.2020.1796451

Perkins, K., Moore, E., Podolefsky, N., Lancaster, K., & Denison, C. (2012). Towards research-based strategies for using PhET simulations in middle school physical science classes. *AIP Conference Proceedings, 1413*, 295-298. https://doi.org/10.1063/1.3680053

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist, 50*(4), 258-283. https://doi.org/10.1080/00461520.2015.1122533

Podolefsky, N. S., Rehn, D., & Perkins, K. K. (2013). Affordances of play for student agency and student-centered pedagogy. *AIP Conference Proceedings, 1513*, 306-309. https://doi.org/10.1063/1.4789713

Pranata, O. D. (2023a). Enhancing conceptual understanding and concept acquisition of gravitational force through guided inquiry utilizing PhET simulation. *Jurnal Sains dan Teknologi, 15*(1), 44-52. https://doi.org/10.31958/js.v15i1.9191

Pranata, O. D. (2023b). Penerapan game-based learning sebagai alternatif solusi mengajar di kelas heterogen [Implementation of game-based learning as an alternative solution for teaching in heterogeneous classes]. *Jurnal Pengabdian Al-Ikhlas, 8*(3), 337-350. https://doi.org/10.31602/jpaiuniska.v8i3.7597

Pranata, O. D. (2023c). Physics education technology (PhET) as confirmatory tools in learning physics. *Jurnal Riset Fisika Edukasi dan Sains, 10*(1), 29-35. https://doi.org/10.22202/jrfes.2023.v10i1.6815

Pranata, O. D. (2024). Students ‘ understanding of vector operations: With and without physics education technology simulation. *Journal of Mathematics and Science Teacher, 4*(3), Article em068. https://doi.org/10.29333/mathsciteacher/14633

Pranata, O. D., & Seprianto, S. (2023). Pemahaman konsep siswa melalui skema blended learning menggunakan lembar kerja berbasis simulasi [Students’ conceptual understanding through a blended learning scheme using simulation-based worksheets]. *Karst: Jurnal Pendidikan Fisika dan Terapannya, 6*(1), 8-17. https://doi.org/10.46918/karst.v6i1.1724

Putri, A. L., Pranata, O. D., & Sastria, E. (2024). Students perception of science and technology in science learning: A gender comparative study. *Jurnal Pijar Mipa, 19*(1), 44-50. https://doi.org/10.29303/jpm.v19i1.6153

Putri, D. H., & Pranata, O. D. (2023). Eksplorasi kejenuhan siswa dalam pembelajaran sains setelah pandemi [Exploring student boredom in science learning after the pandemic]. *Jurnal Inovasi Pendidikan Sains, 4*(2), 62-70. https://doi.org/10.37729/jips.v4i2.3367

Qian, M., & Clark, K. R. (2016). Game-based learning and 21st century skills: A review of recent research. *Computers in Human Behavior, 63*, 50-58. https://doi.org/10.1016/j.chb.2016.05.023

Redish, E. F. (1993). Are computers appropriate for teaching physics? *Computers in Physics, 7*(6), 613-613. https://doi.org/10.1063/1.4823227

Rehn, D. A., Moore, E. B., Podolefsky, N. S., & Finkelstein, N. D. (2013). Tools for high-tech tool use: A framework and heuristics for using interactive simulations. *Journal of Teaching and Learning with Technology, 2*(1), 31-55. https://scholarworks.iu.edu/journals/index.php/jotlt/article/view/3507

Wang, M., & Zheng, X. (2021). Using game-based learning to support learning science: A study with middle school students. *Asia-Pacific Education Researcher, 30*(2), 167-176. https://doi.org/10.1007/s40299-020-00523-z

Whitacre, I., Hensberry, K., Schellinger, J., & Findley, K. (2019). Variations on play with interactive computer simulations: Balancing competing priorities. *International Journal of Mathematical Education in Science and Technology, 50*(5), 665-681. https://doi.org/10.1080/0020739X.2018.1532536

Wieman, C. E., & Perkins, K. K. (2006). A powerful tool for teaching science. *Nature Physics, 2*(5), 290-292. https://doi.org/10.1038/nphys283

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher, 48*(4), 225-227. https://doi.org/10.1119/1.3361987

Winter, J. de, & Hardman, M. (2020). *Teaching secondary physics*. Hodder Education.

Zeng, H., Zhou, S. N., Hong, G. R., Li, Q. Y., & Xu, S. Q. (2020). Evaluation of interactive game-based learning in physics domain. *Journal of Baltic Science Education, 19*(3), 484-498. https://doi.org/10.33225/jbse/20.19.484