Tsaqila Jurnal Pendidikan dan Teknologi [TJPT]
Vol 6 Nomor 1 July 2026, hal: 83-93
ISSN: 2807-6273

Enhancing High School Students' Collaboration Skills and Learning Outcomes through PhET Simulation Based E-Worksheets in Sound Wave Topic

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Abstract

This study was motivated by the low level of students' collaboration skills and physics learning outcomes and by the limited use of digital learning media that simultaneously promote both competencies. Therefore, this study aimed to examine the effect of PhET Simulation-based E-Worksheets on the collaboration skills and physics learning outcomes of eleventh-grade students at SMA Negeri 8 Banda Aceh. A quantitative approach employing a quasi-experimental pretest-posttest control group design was used. Two purposively selected classes participated as the experimental and control groups. Data were collected using pretest-posttest achievement tests, collaboration skills observation sheets, and student response questionnaires. The data were analyzed using descriptive statistics and an independent samples t-test. The results showed that students in the experimental class demonstrated higher collaboration skills than those in the control class. In addition, the experimental class achieved a higher mean physics learning outcome score (M = 76.66) than the control class (M = 65.00). The independent samples t-test indicated a significant difference between the two groups (t_count = 2.37 > t_table = 1.99), confirming that the use of PhET Simulation-based E-Worksheets significantly improved students' physics learning outcomes. These findings provide empirical evidence that integrating PhET Simulation with E-Worksheets not only enhances students' conceptual understanding of physics but also supports the development of collaboration skills, thereby offering an effective instructional strategy for twenty-first-century physics learning.

Keywords: PhET Simulation, E-Worksheets, Collaboration Skills, Learning Outcomes, Sound Waves

1. INTRODUCTION

The rapid development of information and communication technology in the era of the Industrial Revolution 4.0 has brought significant changes in various aspects of life, including education. Educational systems are no longer solely oriented toward knowledge transfer but are also required to equip students with skills relevant to the demands of the 21st century. These skills are formulated in the concept of the 6Cs, namely Character, Citizenship, Critical Thinking, Creativity, Collaboration, and Communication (Anugerahwati, 2019). Mastery of these skills is expected to encourage students to adapt, compete, and actively contribute to global society.

In line with this, education in Indonesia currently faces challenges in developing not only students' cognitive abilities but also their social, emotional, and collaborative skills. Rahmadi, (2023) stated that learning practices in schools still tend to focus on cognitive aspects, while collaboration and communication skills have not been optimally facilitated. In fact, collaboration skills are essential competencies in real-life contexts, both in professional and social environments, as they require individuals to work together, appreciate differences, and take responsibility for shared tasks. Therefore, strengthening collaboration skills has become an urgent issue in physics education, particularly in preparing students to face the increasingly complex demands of the digital era and the future workforce.

The rapid advancement of science and technology demands innovation in learning

strategies. Educational technology serves as an important tool in creating more interactive, contextual, and meaningful learning processes. The integration of technology in learning has been proven to improve the quality of students' learning experiences (Keengwe & Georgina, 2012). Therefore, teachers are required to be more creative and innovative in utilizing technology so that students become more active, critical, and motivated during the learning process (Maulidah, 2019).

Preliminary observations conducted at SMA Negeri 8 Banda Aceh revealed several learning problems. Classroom observations showed that students were generally passive during group discussions, with only a few students actively contributing ideas while others tended to rely on their peers. Interviews with physics teachers also indicated that students experienced difficulties in understanding abstract concepts of sound waves. Furthermore, the average physics achievement score of Grade XI students was 68.4, which was below the school's Minimum Mastery Criterion (KKM) of 75. Only 40% of students achieved the KKM, while the remaining 60% did not meet the required standard. These findings indicate that students' conceptual understanding and participation in physics learning remain unsatisfactory, highlighting the need for instructional innovations that can simultaneously improve cognitive achievement and collaboration skills.

One alternative innovation that can be implemented is PhET Simulation-based E-Worksheets. E-Worksheets are digital developments of conventional student worksheets that can be accessed through computers or mobile devices. This medium allows the integration of various elements such as text, images, videos, and animations, making learning more engaging and interactive (K & Yuliani, 2021). In addition, E-Worksheets can facilitate students in collaborating, discussing, and helping one another in understanding the material.

PhET Simulation, developed by the University of Colorado Boulder, is an interactive simulation medium capable of dynamically visualizing scientific concepts. In physics learning, PhET can bridge the gap between theoretical concepts and real-world phenomena through simulations that can be directly operated by students. Students are not only able to observe but also to explore, manipulate variables, and virtually observe the results. This is in line with the constructivist approach, which emphasizes knowledge construction through direct learning experiences (Finkelstein, 2006).

Several studies have demonstrated that PhET Simulation improves students' conceptual understanding and motivation (Rahmadi, 2023). Likewise, E-Worksheets have been reported to enhance learning engagement and independent learning (K & Yuliani, 2021). However, these studies primarily focused on cognitive achievement or learning motivation as single outcome variables. Only limited attention has been given to collaboration skills, which are increasingly recognized as essential competencies in twenty-first-century learning.

Moreover, previous studies generally examined either the use of PhET Simulation or E-Worksheets separately. As a result, little empirical evidence is available regarding whether integrating interactive simulations with digital worksheets can simultaneously improve collaboration skills and students' conceptual understanding in physics learning. This limitation indicates that the pedagogical potential of combining both technologies remains insufficiently explored, particularly in senior high school physics learning on sound wave topics.

Therefore, the novelty of this study does not merely lie in integrating PhET Simulation with E-Worksheets. Rather, this study provides empirical evidence regarding how the integration of interactive digital worksheets and virtual simulations simultaneously promotes collaboration skills and cognitive learning outcomes within inquiry-oriented physics learning. Unlike previous studies that mainly evaluated cognitive achievement or motivation separately, this study

examines both social and cognitive learning outcomes in a single instructional framework, thereby contributing to a more comprehensive understanding of technology enhanced physics learning.

The findings of this study are expected to contribute to physics education by providing empirical evidence regarding the effectiveness of integrating PhET Simulation into E-Worksheets as an instructional strategy that simultaneously supports cognitive and collaborative competencies. The results may also serve as a practical reference for physics teachers in designing technology-enhanced learning environments aligned with twenty first century educational goals.

Based on the identified research gap, this study aims to investigate the effect of PhET Simulation-based E-Worksheets on students' collaboration skills and physics learning outcomes in senior high school physics learning. Specifically, the study seeks to determine whether integrating interactive simulations with digital worksheets can produce significantly better collaborative competencies and conceptual understanding than conventional instruction.

2. RESEARCH METHODOLOGY

This study employed a quantitative approach using an experimental method aimed at analyzing the effect of using PhET Simulation based E-Worksheets on the topic of sound waves toward students' collaboration skills and physics learning outcomes. The research design used was a quasi-experimental design with a pretest-posttest control group design, involving an experimental class and a control class to compare the results before and after the treatment.

The population of this study consisted of all eleventh-grade science students at SMA Negeri 8 Banda Aceh. The research sample was determined using a purposive sampling technique by considering the equivalence of academic characteristics. Purposive sampling was employed because the researcher could not randomly assign students to different classes due to the existing school administrative policy. The selected classes had comparable academic characteristics based on their previous semester physics scores, were taught by the same physics teacher, followed the same curriculum, and received the same instructional time allocation. These considerations were intended to minimize selection bias and ensure comparability between the experimental and control groups.

The sample consisted of two classes: class XI A2-3, consisting of 30 students, as the experimental class that received learning using PhET Simulation-based E-Worksheets, and class XI A2-1, consisting of 36 students, as the control class that participated in conventional learning. The participants were Grade XI science students aged 16–17 years. Both classes were taught by the same physics teacher, studied the same sound wave topic, and received four instructional meetings with equal learning duration.

The research instruments used in this study included: (1) a learning outcomes test, (2) a collaboration skills observation sheet, and (3) a student response questionnaire. The learning outcomes test consisted of 40 multiple-choice questions covering cognitive domains from C1 to C5, administered in the form of pretests and posttests to measure students' improvement in learning outcomes. The observation sheet was used to observe students' collaboration skills during the learning process, with indicators as presented in Table 1 below.

Table 1
Blueprint of Students' Collaboration Skills Observation Sheet Instrument

Obseved Aspect	Indicator
Collaboration skills	Actively contributing
	Working productively

	Demonstrating responsibility
	Demonstrating flexibility and compromise
	Demonstrating mutual respect

In addition, a student response questionnaire was used to determine students' perceptions of the use of PhET Simulation-based E-Worksheets. The questionnaire was designed using a five-point Likert scale, as presented in Table 2.

Table 2
Blueprint of Student Response Questionnaire

Students' Response Aspects	Indicator	Items number
Students' responses toward the effect of PhET Simulation-based E-Worksheets in physics learning on collaboration skills and learning outcomes	Communication skills within groups	1, 2, 7, 8
	Active participation and cooperation within groups	3, 4, 5, 6, 9, 10
	Understanding and application of sound wave concepts	11, 12, 13, 14, 15, 16
	Motivation and interest in physics learning	17, 18, 19, 20

The study was conducted in four stages. First, a pretest was administered to both the experimental and control classes to determine students' initial physics learning outcomes before the treatment. Second, the treatment was implemented over four learning sessions. In the experimental class, students learned using PhET Simulation-based E-Worksheets in collaborative groups. They explored sound wave concepts through PhET simulations, discussed the results of their investigations, completed the E-Worksheets, and presented their findings. Meanwhile, students in the control class received conventional instruction consisting of teacher explanations, textbook-based learning, printed worksheets, and question-and-answer sessions. Third, students' collaboration skills were observed throughout each learning session using an observation sheet completed by trained observers. Finally, after the completion of the treatment, both classes completed the posttest to measure learning outcomes, and students in the experimental class completed a response questionnaire regarding the use of the PhET Simulation-based E-Worksheets.

The data collection technique was carried out by administering a pretest to determine students' initial abilities, followed by the implementation of the treatment in the experimental class, and ending with a posttest to measure students' learning outcomes after the treatment. Observations were conducted during the learning process to assess students' collaboration skills, while the questionnaire was distributed after the entire learning process was completed to obtain students' responses.

Prior to implementation, all research instruments including the lesson plans, E-Worksheets, learning outcomes test, collaboration skills observation sheet, and student response questionnaire were evaluated by two experts in physics education. The validation assessed content relevance, construct appropriateness, language clarity, and presentation. Each criterion was rated using a four point Likert scale. The average validation score indicated that all instruments were categorized as valid and appropriate for classroom implementation.

Data analysis was conducted through several stages, including questionnaire analysis

using percentages to determine the categories of students' responses, prerequisite tests consisting of a normality test using the Kolmogorov–Smirnov test and a homogeneity test using the F-test to ensure that the data were normally distributed and homogeneous. Furthermore, hypothesis testing was carried out using an independent sample t-test at a significance level of 0.05 to determine the differences in learning outcomes between the experimental and control classes. The testing criteria were determined based on the comparison between the calculated t-value (t_count) and the critical t-value (t_table). To determine the magnitude of students' learning improvement, normalized gain (N-gain) scores were calculated using Hake's formula. N-gain values were categorized as high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), and low ($g < 0.30$). Descriptive statistics, prerequisite tests, normalized gain analysis, and independent samples t-test were performed using Microsoft Excel.

3. RESULT

The results of this study include instrument validity, students' collaboration skills, students' learning outcomes, and students' responses toward the use of PhET Simulation-based E-Worksheets. Data on collaboration skills were obtained through observation sheets, while learning outcomes were measured using pretests and posttests. In addition, the student response questionnaire was used as supporting data to strengthen the research findings.

3.1 Results of Research Instrument Validity

A summary of the instrument validation results can be seen in Table 3.

Table 3
Recapitulation of Instrument Validation Results

No	Instrument	Average	Category
1	Teaching Module Validation Sheet	3.92	Valid
2	Student Worksheet	4	Valid
3	Test Items	3.6	Valid
4	Collaboration Skills Observation Sheet	3.5	Valid
5	Student Response Questionnaire Validation Sheet	3.5	Valid

Based on the instrument validity results presented in Table 3, all research instrument sheets were categorized as valid, falling within the interval of $3.25 < \text{Score} \leq 4.00$, indicating that they were appropriate for use without revision.

3.2 Results of Students' Collaboration Skills Observation

The implementation of students' collaboration skills observation was divided into five indicators: actively contributing, working productively, demonstrating responsibility, showing flexibility and compromise, and demonstrating mutual respect. To assess these five aspects, three observers were assigned to monitor students during group task activities.

The results of the observation of students' collaboration skills indicated differences between the experimental class and the control class, as presented in Table 4 and Table 5 below.

Table 4
Results of Students' Collaboration Skills Observation in the Experimental Class

Indicator	Points Obtained	Total poin	Percentage %
Actively contributing	67	343	74.44%
Working productively	70		77.78%
Demonstrating responsibility	65		72.22%
Demonstrating flexibility and compromise	66		73.33%
Demonstrating mutual respect	75		83.33%

Average students' collaboration skills	**76.22%**

Table 5
Results of Students' Collaboration Skills Observation in the Control Class

Indicator	Points Obtained	Total poin	Percentage%
Actively contributing	75	363	69.44%
Working productively	71		65.74%
Demonstrating responsibility	70		64.81%
Demonstrating flexibility and compromise	69		63.89%
Demonstrating mutual respect	78		72.22%
Average students' collaboration skills			**67.22%**

Overall, the average percentage of students' collaboration skills in the experimental class reached 76.22%, which was categorized as good. Meanwhile, the control class obtained an average percentage of 67.22%, which was categorized as moderate. The higher collaboration score observed in the experimental class suggests that integrating PhET Simulation with E-Worksheets created more opportunities for students to negotiate ideas, share responsibilities, and solve problems collaboratively. The digital worksheet guided students through structured inquiry activities, while the simulation encouraged joint exploration and discussion, thereby strengthening collaborative interactions throughout the learning process. Although no inferential statistical analysis was conducted for the collaboration scores, the descriptive results consistently demonstrated higher performance across all collaboration indicators in the experimental class.

3.3 Results of Data Analysis on Students' Learning Outcomes

The scores obtained from the research were analyzed statistically to examine the learning outcomes of students in the experimental and control classes. Prior to hypothesis testing, prerequisite tests were conducted, namely the normality test and homogeneity test.

3.3.1 Results of the Normality Test

The normality test was conducted to determine whether the research data were normally distributed. The test was processed using Microsoft Excel based on the Kolmogorov–Smirnov formula. The results of the normality test can be seen in Table 6 below.

Table 6
Results of the Normality Test

	Pretest Score		**Posttest Score**	
	Experiment class	Control class	Experiment class	Control class
N Sample	30	36	30	36
Mean	50	47.22	76.66	65
Standard Deviation	25.05	20.36	20.39	19.07
D (Calculated Value)	0.188	0.221	0.135	0.214
KS Table (Critical Value)	0.241	0.224	0.241	0.224
Distribution type	Normal	Normal	Normal	Normal

Since the calculated Kolmogorov-Smirnov statistic for each dataset was smaller than the corresponding critical value (D < KS critical value), indicating that the pre-test and post-test data of the control class and experiment class were normally distributed.

3.3.2 Results of the Homogeneity Test

The homogeneity test was conducted to determine whether the two groups had equal variances. The results of the homogeneity test can be seen in Table 7 below.

Table 7
Results of the Homogeneity Test

	Pretest Score		Posttest value	
	Experiment class	Control class	Experiment class	Control class
F_{count}	1.51		1.11	
F_{table}	1.79		1.79	
Distribution type	Homogen		Homogen	

Based on Table 4.7, the homogeneity test results for the pre-test scores showed that the calculated F-value (1.51) was lower than or equal to the critical F-value (1.79), while for the post-test scores, the calculated F-value (1.14) was lower than or equal to the critical F-value (1.79). Therefore, it can be concluded that the samples of the experimental and control classes had equal variances (homogeneous).

3.3.3 Results of Hypothesis Testing

Based on the results of the normality test and homogeneity test on the post-test scores of the experimental and control classes, it was proven that both classes had normal distributions and equal variances (homogeneous). Therefore, they were appropriate to be used as samples in this study and fulfilled the assumptions for the t-test.

The hypothesis testing in this study was conducted using an independent sample t-test. The results of the hypothesis test can be seen in Table 8 below.

Table 8
Results of Hypothesis Testing

Data	n	$\bar{X}$	t_{count}	t_{table}	Conclusion
Experiment class	30	76.66	2.37	1.99	The hypothesis was accepted.
Control class	36	65			

Based on Table 8, the calculated t-value (2.37) was greater than or equal to the critical t-value (1.99). This result indicates that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) was accepted. Therefore, it can be concluded that the use of PhET Simulation-based E-Worksheets in physics learning had a significant effect on the physics learning outcomes of students at SMA Negeri 8 Banda Aceh.

3.3.4 Results of N Gain Score

To determine the extent of students' improvement in physics learning outcomes after the implementation of the learning intervention, a normalized gain (N-Gain) analysis was conducted. The N-Gain score was calculated based on the difference between the pretest and posttest scores relative to the maximum possible score. The results of the N-Gain analysis for both the experimental and control classes are presented in Table 9.

Table 9
Results of N Gain Score

Class	Pretest	Posttest	N-Gain	Category
Experiment	50.00	76.66	0.53	Moderate
Control	47.22	65.00	0.34	Low

Based on Table 9, the experimental class obtained an N-Gain score of 0.53, which falls into the medium category, while the control class achieved an N-Gain score of 0.34, also categorized as medium. Although both classes showed improvement in learning outcomes, the experimental class demonstrated a higher normalized gain than the control class. These findings indicate that the use of PhET Simulation-based E-Worksheets was more effective in enhancing students' understanding of sound wave concepts than conventional learning.

3.4 Results of Student Response Questionnaire Data

The next stage of data collection involved administering a questionnaire regarding physics learning, which served as supporting data to determine the effect of PhET Simulation-based E-Worksheets in physics learning on students' collaboration skills and physics learning outcomes at the senior high school level. The questionnaire consisted of 20 statement items.

The overall results of the analysis of the student response questionnaire data from the experimental class can be seen in Figure 1 below.

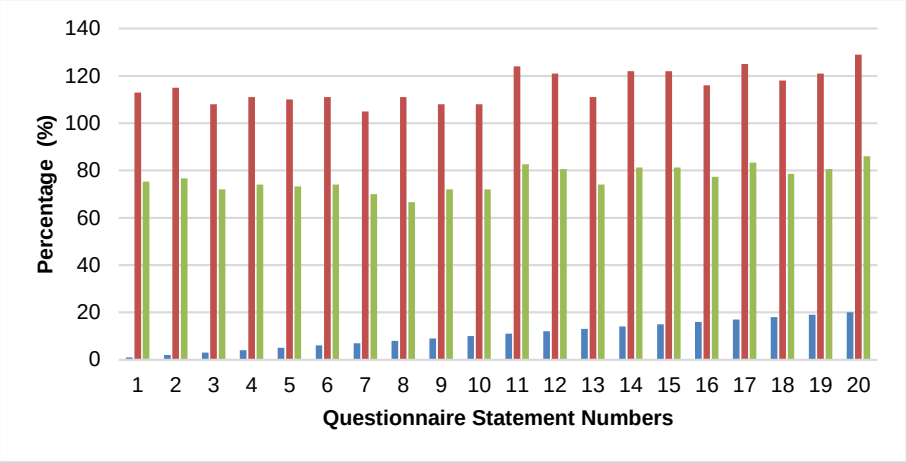

Figure 1
Graph of Student Responses in the Experimental Class

The results of the student response questionnaire showed that the average percentage of students' responses in the experimental class was 76.66%, which was categorized as moderate. This indicates that students gave positive responses toward the use of PhET Simulation based E-Worksheets in physics learning. Overall, the results of this study indicate that the use of PhET Simulation based E-Worksheets was not only able to improve students' collaboration skills, but also had a significant effect on their physics learning outcomes.

4. DISCUSSION

The results of the study showed that the use of PhET Simulation based E-Worksheets had a positive impact on students' collaboration skills and physics learning outcomes. These findings indicate that the integration of interactive digital media in learning can create more meaningful learning experiences and encourage students' active engagement.

In terms of collaboration skills, the observation results showed that students in the experimental class were categorized as good, while those in the control class only reached the moderate category. This difference confirms that learning using PhET Simulation-based E-Worksheets was more effective in facilitating interaction and cooperation among students compared to conventional worksheets. This occurred because E-Worksheets not only provided instructions but also integrated exploratory activities through simulations that required the active involvement of each group member. This finding is in line with Hasan (2025) who stated that E-Worksheet-based learning can improve students' participation and responsibility in group work.

More specifically, the highest achievement in the experimental class was found in the indicator of mutual respect, showing that students were able to build positive communication during discussions. This supports the view Johnson (2009) who argued that mutual respect is

the main foundation for creating effective cooperation. However, the responsibility indicator was still relatively lower than the other indicators, suggesting that some students were not yet fully consistent in carrying out their roles. This is consistent with the theory of Slavin (1995) which emphasizes the importance of individual accountability in successful group work.

In contrast, in the control class, although PhET Simulation was used, students' involvement in collaboration was relatively lower. This was caused by the use of printed worksheets, which were static in nature and less integrated with exploratory activities. Students tended to follow instructions without deep interaction, so their ability to adapt and compromise within the group was also less developed. This finding is consistent with Greenstein (2012) who stated that flexibility and the ability to compromise are important parts of collaboration skills that can only develop through active interaction. Therefore, it can be concluded that the advantage of E-Worksheets lies in their ability to integrate learning activities, discussion, and exploration into one comprehensive medium, thereby promoting more optimal collaboration.

In terms of learning outcomes, the analysis showed that both classes experienced improvement; however, the improvement in the experimental class was more significant than that in the control class. The results of the hypothesis test strengthened this finding, where the calculated t-value was greater than the critical t-value, indicating a significant effect of the use of PhET Simulation-based E-Worksheets on students' learning outcomes. This suggests that learning based on activities and exploration can enhance students' conceptual understanding more deeply. This finding is in line with Anderson & Krathwohl (2001) who stated that active learning experiences enable students to achieve higher-order thinking skills. More recent evidence also confirms that PhET simulations significantly improve students' conceptual understanding and learning achievement when integrated into active instructional settings (Banda & Nzabahimana, 2021).

The improvement in learning outcomes in the experimental class was closely related to the interactive and integrated characteristics of the E-Worksheets. Learning materials, simulations, and exercises were presented within one platform, making it easier for students to understand abstract concepts, particularly in the topic of sound waves. In addition, the flexibility of access allowed students to learn independently outside the classroom. This supports the view of (Arikunto, 2010) who argued that the appropriate use of learning media can improve motivation and learning outcomes. Similarly, recent studies reported that PhET-based virtual laboratory learning significantly enhanced students' learning outcomes and problem-solving abilities in physics classrooms (Warneri et al., 2024).

In contrast, in the control class, the use of PhET Simulation without integration into worksheets made the learning process less optimal, so students' conceptual understanding did not develop maximally. This finding is consistent with the study of (Laelasari et al., 2017), which showed that limited interaction in learning can hinder concept mastery. More recent international evidence also indicates that simulations are more effective when embedded in collaborative instructional environments rather than used individually, because collaboration increases constructive discussion and shared attention among learners (Chen et al., 2021).

The results of this study are also supported by previous research showing that the use of PhET Simulation in physics learning can significantly improve students' learning outcomes and conceptual understanding. For example, a recent meta-analysis involving multiple studies concluded that PhET simulations have a moderate to strong positive effect on physics learning outcomes across educational levels (Fadillah et al., 2025). Thus, it can be understood that the main advantage of PhET Simulation-based E-Worksheets lies not merely in the use of

technology, but in the integration of media, activities, and interactions that support students' knowledge construction processes.

Furthermore, students' responses toward the use of PhET Simulation-based E-Worksheets were categorized as moderate with a positive tendency. Students stated that learning became more interesting, interactive, and helpful in understanding concepts. This indicates that the E-Worksheets had a good level of practicality and were well accepted by students. This finding is in line with (Nieveen, 1999), who stated that practicality is one of the important indicators in assessing the quality of learning materials. Recent studies also found that students perceived simulation-assisted learning as engaging, motivating, and easier for understanding difficult concepts in physics (Taibu et al., 2021).

Although students generally responded positively, the response questionnaire only reached the moderate category (76.66%). This finding indicates that several students still experienced challenges in adapting to technology-assisted learning. Interviews conducted during the implementation revealed that limited experience in operating digital learning media and unequal access to personal devices reduced the effectiveness of several learning activities.

The responsibility indicator obtained the lowest score among the five collaboration indicators. This suggests that some students still depended on more active group members during collaborative tasks. Such findings imply that simply providing collaborative activities is insufficient; teachers also need to establish clear individual responsibilities and monitoring mechanisms during group work.

However, several obstacles were still experienced by students, such as limitations in device usage and adaptation to digital media. This indicates that the implementation of technology in learning needs to be supported by adequate facilities and user readiness. Similar findings were also highlighted in recent studies, which emphasized that technological readiness and access to digital devices remain important factors influencing the effectiveness of e-learning media (Chinaka, 2021; Putra et al., 2023).

Overall, the results of this study indicate that PhET Simulation based E-Worksheets were more effective than conventional worksheets in improving students' collaboration skills and learning outcomes. Their advantages lie in their ability to provide interactive, contextual learning experiences and to encourage students' active participation. In addition, this medium also demonstrated a good level of acceptance among students, making it a feasible and innovative alternative for physics learning in schools. Recent studies further support that combining collaborative pedagogy with PhET assisted learning can significantly improve both collaboration skills and academic achievement compared to conventional approaches.

This study has several limitations. First, the sample was limited to two classes from a single senior high school, restricting the generalizability of the findings. Second, the quasi-experimental design did not allow random assignment of participants. Third, collaboration skills were measured through classroom observation, which may involve observer subjectivity despite the use of standardized observation sheets. Future studies are recommended to involve larger samples, multiple schools, and complementary assessment methods such as peer assessment or self-assessment.

5. CONCLUSION

This study demonstrates that PhET Simulation-based E-Worksheets are more effective than conventional printed worksheets in improving students' collaboration skills and physics learning outcomes. The integration of interactive simulations with digital worksheets not only

enhanced students' conceptual understanding but also promoted active participation and collaborative learning. This study contributes empirical evidence that combining PhET Simulation with E-Worksheets can simultaneously support cognitive achievement and collaboration skills in senior high school physics learning. Practically, these findings provide an alternative instructional strategy for teaching abstract physics concepts. However, this study was limited to a quasi-experimental design involving students from a single school. Therefore, future research should involve larger and more diverse samples and examine the effectiveness of this approach across different physics topics and educational settings.

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