26 (2), 2025, 1025-1043
Jurnal Pendidikan MIPA
e-ISSN: 2685-5488 | p-ISSN: 1411-2531
https://jpmipa.fkip.unila.ac.id/index.php/jpmipa

Improving Elementary Students' Conceptual Understanding of Energy Transformation through a PBL-Integrated with PhET Simulations, Songs, and Gamified Quizzes

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Abstract: The abstract concept of energy transformation is a subject in the natural and social sciences that students frequently find difficult to comprehend. Conventional learning methods are less effective in enabling students to actively engage in the learning process and visualize energy transformation concepts. Consequently, students encounter challenges in comprehending the energy transformation process, the relationship between energy, and examples of objects. The goal of this study is to evaluate how effective problem-based learning, which includes PhET simulations, gamified quizzes, and songs, is in helping fourth-grade students at SD Negeri Losari better understand energy transformation concepts. The quasi-experimental method was employed in this study, with a nonequivalent control-group design. The experimental class IV A consisted of 21 students, while the control class IV B had 20 students. The total number of students in the sample was 41. The total sampling technique was employed in conjunction with nonprobability sampling. Teaching was conducted in the experimental class (IVA) through PhET simulation, gamification, problem-based learning, and melodies. In contrast, the control group (IV B) implemented conventional teaching methods in conjunction with instructional videos. The independent sample t-test and N-Gain test were the methods of statistical analysis. A significant improvement in learning outcomes was confirmed by the independent t-test, which yielded a p-value of less than 0.05. In contrast to the control class, which achieved an average N-Gain score of 0.2678 (low), the experiment class achieved an average N-Gain score of 0.6655 (moderate). This finding suggests that the conceptual comprehension of energy transformation is enhanced through the incorporation of gamified quizzes, songs, PhET simulations, and problem-based learning.

Keywords: PhET simulations, problem-based learning, song, quizzez, energy transformation.

▪ INTRODUCTION

The Merdeka Curriculum, which is presently in use in Indonesia, is a curriculum that incorporates social and scientific subjects into the Natural and Social Sciences at the elementary level. The objective of integrating scientific and social studies subjects is to foster students' ability to comprehend and preserve the environment as a whole, while simultaneously safeguarding both the natural and social environments (Betari, 2023). Students are anticipated to comprehend the interconnectedness of natural and social phenomena and the formation of a complex system as a result of this integration. In order to apply scientific concepts in daily life, students are obligated to think critically, creatively, actively, and scientifically while studying science.

Learners engage in the process of learning in order to acquire new knowledge (Al Naimiy, Bettayeb, Elmehdi, & Shehadi, 2024). The activity of learning is the joint endeavor of teachers and learners to accomplish the anticipated learning objectives (Sewagegn, 2020). The teacher's responsibility in the Merdeka Curriculum is not limited to the mere transmission of knowledge to students; rather, it is to assist students in developing their own profound comprehension. Consequently, in order to enhance

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DOI: http://dx.doi.org/10.23960/jpmipa/v26i2.pp1025-1043
Received: 20 May 2025
Accepted: 14 June 2025
Published: 16 June 2025

student comprehension and knowledge acquisition, educators must implement effective learning media.

Learning media is a tool that serves as an intermediary in the learning process, facilitating the transmission of knowledge and understanding (Charline, Jo, & Frédéric, 2024). Learning media facilitates the process of active knowledge construction, which involves students integrating new information with existing cognitive structures through direct interaction with concrete representations, as per Piaget's constructivism theory (Yildiz, 2025). Piaget's constructivist approach underscores the active role of students in the construction of knowledge through direct experience, social interaction, and meaningful engagement with the learning environment (Satish, 2023). Additionally, multimedia learning theory posits that effective learning requires the simultaneous processing of visual and auditory information through distinct cognitive channels, rendering learning media essential for optimizing information processing (Mayer, 2024). Consequently, in order to accomplish learning objectives, educators must implement meticulous strategies when selecting educational media (Darling-Hammond, Schachner, Wojcikiewicz, & Flook, 2024). All subjects necessitate learning media. In science subjects, learning media facilitate the explanation of abstract and intricate material for instructors.

Many elementary school students continue to experience learning difficulties in science disciplines, with numerous issues identified in fourth grade at SD Negeri Losari. The initial issue is that the concept of energy transformation has not been fully understood by the students. They are unable to comprehend the process or phases of energy transformation from one form to another in a system, the relationship between energy, and examples of objects. Furthermore, conventional methods, such as lectures, are employed in teacher-centered learning. Learning that is predominated by the lecture method without active student engagement has the potential to impede comprehension of the material by causing tedium and reducing interest in learning. The absence of active participation has the potential to diminish students' motivation and interest in learning, resulting in a suboptimal comprehension of the material (Algorashi & Mohammed, 2024). Secondly, the cognitive learning outcomes of class IV students on energy transformation material are still low. The Minimum Completion Criteria was only met by 9 out of 21 pupils (43%) in Class IV A, as illustrated in Figure 1. In contrast, the Minimum Completion Criteria was achieved by only 9 out of 20 pupils (45%) in class IV. An additional issue is the restricted selection of educational media. Whiteboards, worksheets, and YouTube videos are the sole educational resources employed by educators.

The dynamic process of energy transformation cannot be perpetually demonstrated through the use of whiteboards and worksheets, as they only provide static representations. The passive nature of YouTube videos prevents students from interacting with or manipulating variables in order to investigate a variety of energy transformation scenarios. Students encounter challenges in comprehending the abstract concept of energy transformation and connecting it to real-world phenomena due to the constraints of conventional media. Furthermore, teachers are also impeded in their ability to develop students' comprehension in a profound and meaningful manner through practicum activities due to the availability of limited resources, such as practicum instruments. Practicum activities are not merely a supplement to science education; they are essential for the development of profound comprehension (García-Noblejas, Barceló-Cerdá, Rodríguez-Gómez, & López-Gómez, 2023). Students are not only passively learning theory but also actively participating in the discovery process through practicum activities (Kahila, Kuutti, Kahila, & Sajaniemi, 2024). Practical activities offer students the chance to directly validate and experiment with concepts, resulting in a more profound and visual comprehension than merely listening to explanations (Shana & Abulibdeh, 2020).

Nevertheless, the absence of practicum activities in learning is a result of the lack of laboratory facilities, which includes practicum instruments and materials. In the current digital era, virtual laboratories, such as PhET simulations, are a solution to these issues. This PhET simulation offers students the opportunity to experiment digitally. This simulation is highly interactive and engaging, which motivates students to engage in active exploration in order to cultivate a more profound conceptual comprehension (Diab, Daher, Rayan, Issa, & Rayan, 2024). PhET simulations are more effective in facilitating students' comprehension of concepts in depth (Banda & Nzabahimana, 2021). Students will attempt to resolve an issue by employing a PhET simulation in the energy transformation material. The source of energy, its converter, and its utilization will be identified, and the process of change will be explained. Consequently, PhET simulation activities facilitate their comprehension of the abstract concept of energy transformation. Students are able to comprehend scientific concepts through the use of PhET simulations (Dy, Lagura, & Baluyos, 2024).

The synergistic effect of the learning approach that incorporates PhET simulations, learning melodies, gamified quizzes, and Problem-Based Learning (PBL) is greater than that of the component elements used individually. Maximizing pupil engagement, retention, and comprehension, this multimodal and holistic approach integrates a variety of sensory modalities with complementary cognitive and social components. This is consistent with multimodal learning theory, which underscores the significance of simultaneously presenting information through multiple sensory channels, including visual, auditory, and kinesthetic, to improve cognitive processes and fortify long-term memory (Mayer & Fiorella, 2021). The PhET simulation will be reinforced by a learning melody in its application, which can enhance student engagement in the learning process and facilitate long-term memory retention. Inviting students to perform is one method of establishing a fun learning environment. The learning environment will be rendered more enjoyable and thrilling by the collective singing (Sutikno, Jazuli, Utomo, & Sunarto, 2024). Therefore, this educational melody can facilitate students' retention of examples of energy transformation in their surroundings and increase their enthusiasm for learning. In addition to harmonizing together, quizzes can be implemented to establish a learning environment. The genially quiz platform uses a gamification approach by incorporating leaderboard elements and a point system to provide students with feedback on their comprehension of the material, increase their interest and engagement in the learning process, and aid in their retention of the material (Cigdem, Korkusuz, & Karaçaltı, 2024). The competitive environment that prevails during the exam can serve as an incentive for students to engage in the learning process by responding to inquiries concerning the energy transformation material. Students are able to reinforce and retain the energy transformation material they have acquired through the PhET simulation by responding to these questions.

Learning will be facilitated by Problem-Based Learning in order to optimize the implementation of PhET simulations. The problem-based learning (PBL) paradigm is a learning approach that prioritizes the resolution of real-world problems. In contrast to traditional approaches, Problem-Based Learning prioritizes students and involves educators in motivating their active engagement. Students are given a dynamic role in the learning process in the PBL model. They collaborate with their peers in groups and participate in problem-solving activities (Yaşar, Batdi, Kiliç, & Yilmaz, 2024). In the application of the PBL paradigm to energy transformation material, students will be presented with problems in the form of energy transformation case studies that are encountered in daily life. Subsequently, they will resolve these problems using PhET simulations.

Song-assisted learning media has been demonstrated to have a positive impact on the learning process in numerous previous studies. Student learning outcomes in science are substantially enhanced by the incorporation of songs into the learning process. Students are more likely to retain and comprehend material concepts when they are presented in an engaging manner in song lyrics (Wati & Sutikno, 2024). PhET simulations are effective in facilitating students' comprehension of the concept of learning materials (Maulida, Taufik, & Kosim, 2022). Nevertheless, the integration of PhET simulation media with melodies that are supported by the Problem-Based Learning model has not been addressed in any of the numerous previous studies. The utilization of gamified exams is an additional distinctive aspect of this investigation. Consequently, the objective of this investigation is to evaluate the efficacy of the application of PhET simulation media, which is accompanied by songs and genially gamified quizzes, in conjunction with Problem-Based Learning, as a solution to enhance the learning outcomes of science material on energy transformation for fourth-grade primary school students. Additionally, the research questions that underpin this study are as follows: Does the integration of Problem-Based Learning with PhET simulations, song, and gamified exams enhance the conceptual comprehension of energy transformation among fourth-grade students at SD Negeri Losari?

▪ METHOD

Participants

The research was conducted at SDN Losari in the Temanggung Regency. The experimental group consisted of 21 students in class IVA, while the control group consisted of 20 students in class IVB. The research population consisted of fourth-grade pupils from SDN Losari. The educational level and learning material are identical in both the control and experimental courses. A pretest was administered to assess the initial energy transformation capabilities of the students in order to guarantee initial equality between the two groups. The pretest results indicated that the average scores of the two groups were comparatively equal, suggesting that there were no significant differences in the initial abilities of students between the experimental and control groups. The application of the assessed learning media was attributed to the differences in learning outcomes that emerged after the treatment, as this equality served as a strong foundation for the conclusion. The sampling method employed was nonprobability sampling. This decision was predicated on the restricted and specific characteristics of the research population, which consisted of all fourth-grade pupils at a single school. Researchers were able to maximize representation and eliminate potential sampling error by involving all relevant members of the population through the use of total sampling, a form of nonprobability sampling, due to the small number. Sugiyono (2016) defines nonprobability sampling techniques as methods of selecting samples that do not offer equal opportunities for each individual or unit in the population to be included in the sample. Gay and Diehl (1992) contend that "the minimum sample size for experimental research is 15 subjects per group." (A'izah & Dewi, 2024). The sampling technique employed in the investigation was saturated sampling. Saturated sampling is a methodology that employs the entire population as the sample, as per Sugiyono (2021). Thus, the experimental group consisted of all class IVA (21 students) and the control group consisted of all class IV (20 students) from SDN Losari.

Research Design and Procedures

This research employed a quasi-experimental methodology in conjunction with a quantitative approach. The research design implemented was a Non-Equivalent Control Group Design, which included pretest and posttest procedures (Sugiyono, 2019). Before the treatment was administered, the experimental class (IV A) and the control class (IV B) completed a pretest to assess their initial capabilities. The pretest, which lasted for 60 minutes, consisted of 10 essay questions. Next, the experimental class (IV A) received a unique approach that included the use of Physics Education Technology (PhET) media to teach Natural and Social Sciences, which was accompanied by gamified exams and songs, as well as problem-based learning. The teacher initiates the learning process by presenting contextual problems that are pertinent to the students' daily activities. Subsequently, students engage in group discussions and explorations to resolve the issues through the use of PhET simulations. Each group presented their discussion results at the front of the class after conducting virtual experiments through the simulations. The teacher then reinforced the concepts and encouraged reflection. Next, students collaborate to perform the song "Energy Transformation." This is followed by the development of a gamified exam in groups using Genially. Concurrently, the control class employs video learning media in conjunction with a conventional learning model, which involves a lecture and question-and-answer format that is moderated by the instructor. The material is presented in a PowerPoint presentation that includes significant learning elements and is accompanied by a 5- to 10-minute educational video. The concept of energy transformation is elucidated in the video through the use of simple visual illustrations and narration. Additionally, the content of the material was modified to correspond with that of the experimental class. Consequently, it was anticipated that the variations in learning outcomes would be attributable to variations in the learning approach rather than disparities in the quality or quantity of the material. The experimental and control courses conducted the lesson in four sessions, each of which lasted 70 minutes. Post-tests were administered to both classes following the treatment phase to ascertain the learning outcomes of the pupils and identify any discrepancies.

Instruments

Interview guidelines, observation guidelines, learning modules, test instruments, pretest and posttest queries, and documentation were implemented. In order to ascertain student abilities, learning models, and characteristics, unstructured interviews were conducted with classroom instructors as an initial needs analysis. Subsequently, observation activities were implemented to monitor the learning process and student interactions within the classroom. The teaching modules that were created in this study are derived from Chapter A of Natural and Social Sciences Grade 4 Semester 2: Energy Transformation in the Environment. The researcher employed two distinct teaching modules in this investigation, one for the experimental class and the other for the control class. Each module was intended to accommodate four meetings. These two modules contain eight learning outcome indicators, which are categorized as six indicators in the cognitive domain, one indicator in the affective domain, and one indicator in the psychomotor domain. The approach, structure of activities, and emphasis on learning are the primary distinctions between the teaching modules for the experimental and control classes. The experimental class module employs an interactive PhET media platform and a Problem-Based Learning (PBL) approach, which prioritizes student engagement in concept exploration, discussion, and problem resolution. In contrast, the control class module employs a conventional approach, which involves lectures and question-and-answer sessions, with learning videos serving as the primary medium. The modules were validated by subject matter experts and media experts prior to their implementation. The assessment results indicated that the modules were highly suitable, with subject matter experts rating them at 89% and media experts rating them at 85%.

The validity, reliability, difficulty level, and discriminating power of the test instruments were initially assessed prior to their implementation in the study. 20 candidates were tested. Twelve essay questions comprised the instrument examination. In Inwanti (2025), validity determinations were made using the r table value, a two-tailed test, and a significance level of 0.05, as per Pariyanto (2016). The instrument was pronounced valid if the correlation value was either greater than or equal to the specified limit (r calculated ≥ r table). In contrast, the instrument is considered invalid if the correlation value is less than the specified limit (calculated r < table r) (Inwanti & Setiawan, 2025). The Cronbach Alpha value is a metric that can be used to ascertain the reliability or consistency of a variable in measurement. The value is regarded as reliable or consistent if it exceeds 0.60 (Taherdoost, 2018). Arikunto (2013) classifies difficulty levels 0.00-0.30 as hard, 0.3-0.70 as medium, and 0.71-1.00 as simple (Fitriani, 2021). The interpretation of the interval discriminative power is as follows, as per Arikunto (2013) in Fitriani (2021): 0.00-0.19 is considered inadequate, 0.20-0.39 is adequate, 0.40-0.69 is good, and 0.70-1.00 is very good (Fitriani, 2021).

Only 10 of the 12 questions fulfilled the validity, discriminative power, reliability, and difficulty index criteria after calculating them using Excel, rendering them suitable for use. Consequently, this investigation employed ten essay questions in both the pretest and posttest to ascertain the learning outcomes of fourth-grade students prior to and subsequent to the intervention. The total maximum score for 10 questions is 40 points, as the maximum score for each question is 4 points. In order to determine the final score on a scale of 100, the student's raw score is divided by 40 (the utmost score) and the resulting number is multiplied by 100. The researcher adjusted the predetermined learning objective indicators, which were composed of six learning objective indicators, to devise the questions used in the pretest and posttest. The cognitive abilities of students were assessed through the developed question/assessment indicators, which were based on the cognitive domain C4 (Analyzing).

Data Analysis Techniques

The data in this study were subjected to hypothesis testing with the aid of SPSS version 24. Prior to conducting hypothesis testing, the pretest and posttest scores of students were evaluated to guarantee that the data is homogeneous and distributed normally. The Shapiro-Wilk formula was employed to evaluate data normality, as the sample size was less than 50. The Levene test was employed to determine homogeneity. An independent samples t-test was used to determine whether there was a substantial difference in learning outcomes between the control and experimental groups after the data normality and homogeneity were confirmed. A significance level of $p < 0.05$ was employed in this analysis. Furthermore, an N-Gain test was implemented to evaluate the intervention's efficacy in enhancing student learning outcomes. The value of N-Gain is between -1 and 1. "N-Gain" is also known as "normalized gain" or "normalized improvement." N-Gain is an extensively used analytical tool in the field of educational research (Sukarelawa, Indratno, & Ayu, 2024). The N-Gain Values were classified into six levels: Decrease ($1.00 \leq g < 0.00$), No increase ($g = 0.00$), Low ($0.00 < g < 0.30$), Middle ($0.30 \leq g \leq 0.70$), High ($0.70 \leq g \leq 100$) (Sukarelawa et al., 2024). The criteria for determining the effectiveness level are as follows: Ineffective (<40), Less effective (40-55), Quite effective (56-75), and Effective (>76) (Sukarelawa et al., 2024).

▪ RESULT AND DISSCUSSION

The objective of this investigation is to evaluate the efficacy of Problem-Based Learning integrated with PhET simulations, song, and gamified assessments in order to enhance the conceptual comprehension of energy transformation. In the experimental cohort, the high average posttest scores and N-Gain values are indicative of this improvement. This suggests that the intervention is effective in assisting students in the acquisition of a comprehensive understanding of a variety of fundamental concepts related to energy transformation, including the analysis of energy sources, forms of energy, energy transformation processes in hydroelectric power plants (PLTA) and solar power plants (PLTS), examples of energy transformation in everyday life, multi-stage energy changes, and the relationships between energies. Research was conducted in fourth-grade A (experimental class) and fourth-grade B (control class). The PBL method was implemented in four sessions to provide instruction to the experimental class in this investigation. At the initial meeting, students were assigned a problem or case study that was associated with the fluctuations in the energy process of solar panels (PLTS). The teacher provides an understanding of the fundamental concepts of energy transformation, including the definition of energy, energy sources, various energy sources, the law of conservation of energy, forms of energy, and various types of energy transformations in everyday life, before students solve the problem. The teacher introduces the concept of energy transformation by utilizing the PhET simulation after providing a comprehension. Then, they collaborate to resolve a problem by investigating the use of PhET simulation media in groups. Students acquired an understanding of the phases involved in the conversion of motion energy into electricity during the second meeting. Students resolve an issue by investigating the PhET simulation. Students acquire an understanding of the phases of the transformation of potential energy into electrical energy that transpire in hydroelectric power plants (PLTA) during the third meeting. Students resolve an issue by investigating the PhET simulation. Students conclude the relationship between energy and complex systems during the fourth meeting. Through the examination of PhET simulations, students resolve an issue that arises in solar power plants and hydropower plants.

The incorporation of gamified quizzes, songs, Problem-Based Learning (PBL), and PhET simulations results in a multiplicative effect that enhances students' comprehension of energy transformation concepts. The PBL context offers a focused framework for the exploration of PhET simulations, in which students solve problems that are pertinent to their daily lives, such as the transformation of energy in solar panels, by utilizing PhET simulations. The Problem-Based Learning model produces a sense of purpose and orderliness when investigating PhET. The song's lyrics provide a concise explanation of energy transformation examples that are simple to recall. Students' involvement in the learning process is enhanced by this methodology. They engage in discussions when resolving worksheet issues. Additionally, the gamified assessments serve to reinforce students' comprehension of energy transformation illustrations. Students simultaneously recall the visual images from the PhET simulation, the conceptual comprehension acquired from the PBL group discussions, and the lyrics of the energy transformation concepts remembered from the song when they answer questions in the quiz. This memory-building process, which integrates all of these components, provides students with a more robust and enduring comprehension. Furthermore, the quiz format, which is modeled after a game, fosters a greater sense of interest and motivation among students, thereby making the process of retaining the material more pleasurable.

Conventional methods were employed to conduct the lesson in the control class, which involved the viewing of educational recordings. The teacher utilized PowerPoint and a video presentation to present the material on energy transformation. The teacher provided an explanation, which was followed by a discussion and a presentation in front of the class. The students listened attentively. This approach is more teacher-centered, as students are inclined to passively listen to the explanations. Despite the fact that PowerPoint and video aid in the visualization of the concept of energy transformation, their comprehension is restricted to the information provided, as they lack a profound learning experience in comparison to experimental class students who utilize PhET simulation media in conjunction with songs that facilitate Problem-Based Learning (PBL).

Before the intervention was administered, learners in the control and experimental classes completed a pretest to evaluate their learning outcomes. Additionally, the experimental class participated in a scientific learning session that utilized PhET media and songs to explore the topic of energy transformation in the environment, as part of Problem-Based Learning (PBL). In contrast, the control class exclusively employed conventional video-based learning, which did not include PhET simulations or supplementary tunes. the display of PhET simulation media utilized in experimental classroom learning.

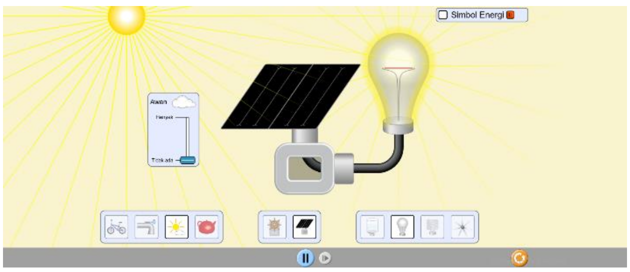

Figure 1. PhET simulation media display

PhET simulation media can be accessed on the website https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_in.html as shown in Figure 1. PhET media was chosen because it can visualize the process of energy change. In this study, experimental class students conducted simulation and exploration activities using PhET media. Learners can determine the source of energy, the converter, and examples of its use. To further enliven the classroom atmosphere and increase learners' understanding of examples of its use in everyday life, PhET media is assisted by the song “Energy Transformation’’. The following are the lyrics of the song “Energy Transformation”

Transformasi Energi

Energi adalah kemampuan benda
Untuk melakukan kerja atau usaha
Energi itu ada bentuk-bentuknya
bentuk yang bisa mengalami perubahan

Gerak energi gerak, panas dan, dan juga listrik
Ada kimia bunyi juga cahaya
Energi listrik bisa berubah jadi bunyi
contohnya ada pada televisi

Listrik ke bunyi contohnya Radio
Listrik ke cahaya contohnya lampu. TV
Listrik kepanas contohnya setrika
Listrik jadi gerak contohnya blender kipas

Jika kamu amati itulah benda-benda
Yang mengalami transformasi energi
Lalu Coba sebutkan energi apalagi
Yang mengalami transformasi energi

Figure 2. View of the lyrics of the song “Transformasi Energi”

The lyrics of the song "Transformasi Energi" by Indah Sdr are illustrated in Figure 2. This song was not expressly composed for this investigation; rather, it was selected due to the fact that its lyrics contain critical terms that are pertinent to the concept of energy transformation. https://youtu.be/aFeDFOVPc2k?si=DztQY-r_0gzYd6qH is the link to access the song. The genially gamified exam was completed by the experimental class in groups. The quiz that is genially gamified is illustrated below.

Figure 3. Display of the genially modified quiz

This quiz contains questions related to energy transformation material. This quiz can test students' understanding of learning materials in a fun way. Then, both classes were given post test to measure their learning outcomes on energy transformation. The pretest and posttest results for both classes are shown in Figure 4.

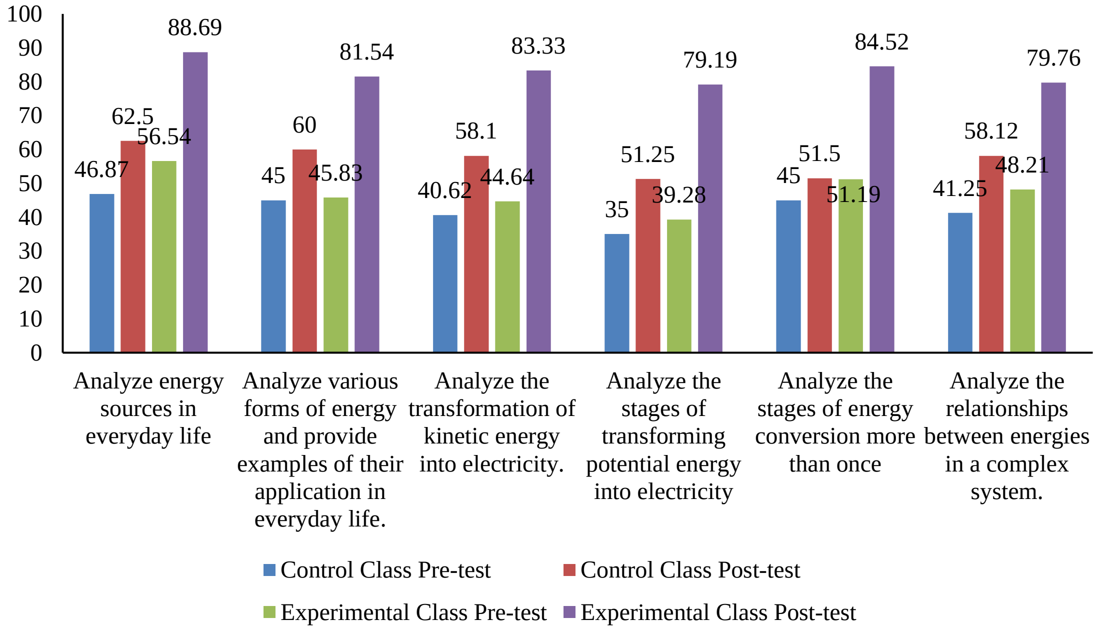

Figure 4. Mean pretest and postest result

As demonstrated in Figure 4, student learning outcomes on six indicators show that the experimental class experienced a higher increase than the control class. The pretest scores between the two classes were relatively similar, ranging from 35.00 to 46.87 in the control class and 39.28 to 56.54 in the experimental class. After learning, the control class improved moderately (51.25-62.5), while the experimental class exhibited significantly higher post-test scores compared to the control class, ranging from 79.19-88.69. This confirming a statistically significant difference. This increase occurred because the use of PhET simulation supported by songs and gamified quizzes with the application of PBL was able to improve conceptual understanding of energy transformation.

After obtaining pretest and posttest data, these data are tested for prerequisites using normality and homogeneity tests. In this study, the Shapiro-Wilk formula was used for normality testing, with a significance level above 0.05 indicating a normal distribution of research data. Meanwhile, a significance level below 0.05 showed abnormal data distribution. Data normality test results using SPSS 24 can be seen in Table 1.

Table 1. Normality test results

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Kelas	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Results	Control Class Pre-test	.137	20	.200*	.962	20	.578

	Control Class Post-test	.233	20	.006	.933	20	.174
	Experimental Class Pre-test	.217	21	.011	.940	21	.219
	Experimental Class Post-test	.167	21	.130	.912	21	.061
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

According to Table 2, both the pre-test and post-test data for the experimental and control groups exhibited values exceeding 0.05, thereby confirming their normal distribution for subsequent analysis. The homogeneity test was conducted with the specific aim of determining whether the two samples possessed equivalent variances. The formula used in this study is the Levene test.

Table 2. Homogeneity test results

		Levene Statistic	**df1**	**df2**	**Sig.**
Result	Based on Mean	2.060	1	39	.159
	Based on Median	1.498	1	39	.228
	Based on Median and with adjusted df	1.498	1	38.999	.228
	Based on trimmed mean	2.004	1	39	.165

Based on Table 2, the data show the same variance or homogeneity. This result is supported by a mean significant value of 0.159, exceeding the threshold of 0.05. As the data were normally distributed and homogeneous, hypothesis testing to compare learning outcomes between the two groups could be conducted using an independent samples t-test. When testing hypotheses, a significance (2-tailed) value of less than 0.05 indicates that the null hypothesis (H0) should be rejected and the alternative hypothesis (H1) accepted. This finding reveals a statistically significant difference in learning outcomes when comparing the experimental and control groups. Conversely, when the Sig. value (two tails) exceeds 0.05, the null hypotheses are retained, indicating no differences in the average learning outcomes of the two groups.

Table 3. The results of independent sample t-test

	Levene's Test		**t-test**						
Equal variances assumed	**F**	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**SE Difference**	**95% CI Lower**	**95% CI Upper**
Indicator 1	.080	.779	-7.606	39	.000	-25.595	3.365	-32.402	-18.789
Indicator 2	.063	.803	-5.289	39	.000	-21.548	4.074	-29.788	-13.307
Indicator 3	.812	.373	-9.039	39	.000	-25.804	2.855	-31.578	-20.030
Indicator 4	2.520	.121	-6.369	39	.000	-26.131	4.103	-34.429	-17.832
Indicator 5	2.099	.155	-4.991	39	.000	-23.274	4.664	-32.707	-13.841
Indicator 6	.573	.454	-6.524	39	.000	-22.232	3.408	-29.125	-15.339

Notes: Indicator 1-6 are analyze energy sources in everyday life, analyze various forms of energy and provide examples in everyday life, analyze the stages of transforming kinetic energy into electricity, analyze the stages of transforming potential energy into electricity, analyze the stages of energy changes occurring more than once, and analyze the relationships between energies in a complex system, respectively

Table 3 displays a significance value of 0.000 for each indicator, which is less than the threshold of 0.05. This indicates that there is a substantial disparity in the learning outcomes of the control and experimental classes. This results in the rejection of H0 and the acceptance of Ha, thereby confirming that students in the experimental class, who utilized PhET simulations supported by songs with a Problem-Based Learning model, achieved superior learning outcomes in energy transformation material when contrasted with students in the control class, who utilized conventional videos. Consequently, it can be concluded that the enhancement of scientific learning outcomes is positively influenced by PhET simulations that are accompanied by songs that employ a Problem-Based Learning model.

The N-Gain Test was employed to evaluate the efficacy of the learning process, which evaluates the increase in students' scores from the pretest to the posttest. The experimental class's average N-Gain is 0.6655, qualifying it as moderate or fairly effective ($0.30 \leq g \leq 0.70$). This value is a clear indication that the intervention, which involves the integration of PhET simulations with songs, gamification, and the Problem-Based Learning (PBL) model, has been effective in enhancing the science learning outcomes of fourth-grade elementary school students on the subject of energy transformation. This effectiveness includes the capacity of students to analyze energy sources and various forms of energy, as well as examples in everyday life. It also includes the ability to analyze the stages of energy transformation from kinetic energy to electrical energy and potential energy to electrical energy, describe the stages of energy transformation multiple times, and conclude the relationships between energies in complex systems. In contrast, the control class exhibited an average N-Gain of 0.2678, which is classified as low or ineffectual ($0.00<g<0.30$). This suggests that the control class's conventional teaching method was ineffective in improving students' conceptual comprehension of energy transformation or yielded minimal improvement in learning outcomes.

The outcomes of science learning are significantly enhanced by the use of PhET simulation media that is accompanied by melodies and a Problem-Based Learning approach, according to research findings. This is evident in the average posttest scores of students in the experimental class, which utilized PhET simulation supported by songs with a Problem-Based Learning model, which were 83.28. This score was higher than that of the control class, which utilized instructional videos with a conventional method, which was 59.25. These results are consistent with a study conducted by Andri (2024), which indicates that the average value of student understanding in classes that utilize PhET simulations is greater than that of control classes that do not use PhET simulations (Sopari, Kurnia Jayadinata, & Ismail, 2024). Furthermore, students' interviews indicated that the learning experience was more pleasurable when students were instructed using PhET simulation media that was accompanied by songs and a problem-based learning approach. They disclosed that the integration of PhET simulation visualizations with song patterns and lyrics facilitated their comprehension of abstract scientific concepts that were previously regarded as challenging, including energy transformation. Rayan (2023) conducted a study that demonstrated that PhET simulation enhanced students' knowledge and engaged them in the learning process. (Rayan, Daher, Diab, & Issa, 2023). This discovery is consistent with Piaget's constructivist theory, which emphasizes that students construct their own knowledge through authentic experiences during the learning process (Halid et al., 2024).

The video learning media utilized in the control class was of high quality and effectively conveyed energy transformation concepts in a visually appealing manner. However, conventional videos often result in students being passive recipients of information. In contrast, the experimental classroom lessons that utilize PhET simulations, which are supported by the PBL model, encourage students to actively engage in the learning process. This is due to the fact that students are not only able to hear and receive abstract energy transformation material from the teacher, but they are also able to observe, investigate, and verify their comprehension without being restricted by laboratory equipment. Students can investigate and observe energy sources, their modifiers, and examples of their utilization through the PhET simulation's interactive features and visually appealing interface. Students can elucidate the process of energy transmutation from one form to another through this exploration process. The simulation also allows students to adjust variables, including the intensity of sunlight, the pace of the wind, and the quantity of food consumed. Students can ascertain that energy is interconnected by observing these changes. PhET simulations not only assist students in comprehending the concept of learning materials but also enhance student engagement in the learning process and enhance student learning outcomes through the use of interactive features and visually appealing visualizations (Buday Benzar M, Dalisay, Christi Norma C, Emralino Blaisie S, & Laurio Shiela Lyn R, 2023).

Furthermore, the utilization of songs as educational aides enhanced students' academic performance. The integration of singing activities with melodies enhances students' comprehension of the examples of energy transformation. Additionally, singing activities foster an enjoyable learning experience and enhance their enthusiasm. This discovery is consistent with Tavadze's (2021) prior research, which demonstrated that singing in unison can foster a positive and enjoyable learning environment (Tavadze, Diasamidze, & Katamadze, 2021). Repeatedly singing songs can assist students in the retention and memorization of educational materials (Khidirova, 2021). These results are in accordance with the research conducted by Syawalia (2023) that students are able to retain learning material when melodies are incorporated into the learning process. (Syawalia, Putri, & Prayogo, 2023). Conducting research Kamila (2025) elucidates that the utilization of songs in the learning process can facilitate the comprehension and retention of science concepts that are perceived as challenging, while also creating a pleasurable learning environment (Kamila & Sutikno, 2025). The concepts of the material are more easily comprehensible to students when they are taught using melodies. (Makarima & Sutikno, 2024).

Additionally, the utilization of genially gamified quizzes enhances students' comprehension and ensures that the material is retained in their long-term memory with respect to energy transformation in an enjoyable manner. The questions in the genially gamified exam are intended to assess the comprehension of the concept of energy transformation that was uncovered during the exploration with the PhET simulation. Furthermore, the inclusion of this gamification exercise enhances student motivation. The utilization of genially gamified assessments enhances student motivation and engagement during the lesson (Hermita et al., 2022). The presence of a leaderboard system and points for each question stimulates students' interest and fosters healthy competition among groups in the completion of quizzes, thereby facilitating an enjoyable learning experience. Groups that achieve the highest score will receive incentives from their peers. In conjunction with the awarding, student motivation is likely to rise (Winangsih & Harahap, 2023). Habibie, Tolaki, and Sartika (2025) assert that gamification in learning can establish an engaging and enjoyable learning environment, which is consistent with their research. Jaramilo (2024) conducted research that demonstrates that gamification in learning can foster a positive environment, enhance motivation, and enhance student engagement in the learning process (Jaramillo-Mediavilla, Basantes-Andrade, Cabezas-González, & Casillas-Martín, 2024). This is consistent with the aforementioned.

Problem-Based Learning (PBL) facilitates the implementation of educational media. The learning process commences with the teacher presenting a problem that is pertinent to the students' lives, such as the question of why one house has its lights on while the surrounding houses have them off. What are the energy sources that are utilized, and how is the energy transformation process conducted? Subsequently, students engage in group discussions and explorations to resolve these issues through the use of PhET simulations. Each team presented their discussion results in front of the class after conducting virtual experiments through PhET simulations. The session concluded with reflection and reinforcement from the teacher. This model of Problem-Based Learning enhances students' comprehension of energy transformation in relation to their daily lives.

Problem-Based Learning offers students a contextualized learning experience by facilitating the resolution of problems that are pertinent to their daily lives. Consequently, students can perceive a direct correlation between their academic pursuits and their personal lives (Knöpfel, Kalz, & Meyer, 2024). Students are anticipated to engage in a collaborative effort to identify solutions by employing authentic and pertinent issues (Amerstorfer & Freiin von Münster-Kistner, 2021). According to Babo, Mendonça, and Pinto (2024), Model Problem-Based Learning situates students at the forefront of the learning process, empowering them to identify and resolve issues. PBL entails students identifying solutions to issues that are pertinent to their daily lives. PBL is a learning process that entails the presentation of students with real-world problems in order to foster critical thinking, develop their problem-solving skills, and identify a variety of solutions (Widiastuti, Mantra, Utami, Sukanadi, & Susrawan, 2023).

The results of this study suggest that the conceptual understanding of energy transformation of students in the experimental class was significantly higher than that of students in the control class. This suggests that the learning process was more effective when using PhET simulation media, which was supported by songs and gamified quizzes with problem-based learning. Nevertheless, this investigation is characterized by a relatively small sample size and a lack of control over confounding variables. In order to enhance future research, it is advised that a larger sample size be employed and that more stringent controls be implemented to reduce the impact of external factors on the experimental group. Additionally, the optimization of learning outcomes in other subject areas is promoted through the ongoing research and development of PhET simulation media, which are augmented with songs and Genially-based gamified quizzes.

▪ CONCLUSION

PhET simulation media, which are accompanied by songs and genially gamified assessments with Problem-Based Learning, have been shown to be an effective approach in enhancing conceptual understanding of energy transformation in comparison to conventional video media. A virtual exploration experience is provided by PhET simulation learning media, which thereby facilitates students' comprehension of abstract concepts without the constraints of learning aides. Furthermore, the use of songs can enhance students' comprehension of energy transformation material, including specific examples of energy transformation in ordinary life. Additionally, students' engagement in the learning process is enhanced by the use of genially gamified assessments, which serve to reflect the comprehension they acquire during their exploration of PhET simulations.

Therefore, learning media is an essential component that researches or practitioners in the field of education must investigate. Instructional media should be customized to accommodate the digital sector's advancements and the requirements of students. This discovery implies that educators should optimize the utilization of PhET simulation media, which is equipped with songs and genially gamified assessments, in conjunction with a problem-based learning approach, to enhance the learning outcomes of energy transformation science. Additionally, learners are able to cultivate critical problem-solving abilities that are necessary for addressing real-world obstacles through the implementation of PBL.

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