The Influence of Simulation Videos and Problem-based Project Learning on Students' Creativity in Making Simple Physics Products

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ABSTRACT

In this study, the creativity of physics education students was analyzed through a descriptive qualitative approach while they designed and produced simple physics products using simulation videos and Problem-based Project Learning (PJBL). This study focused on the application of the principles of thermodynamic energy and renewable energy in the construction of water-powered toy cars. Students took part in PJBL that included the watching of simulation videos that were designed to explain difficult physics concepts so as to motivate creative solutions. Participant observation, interviews, and documentation of student reports, sketches, and prototypes were used as data collection methods. Meeting the four creativity criteria: originality, fluency, flexibility, and elaboration drove the analysis. Findings indicate that simulation videos enhanced thermodynamic process visualization and re-imaginative processes, increasing originality. PJBL enhanced flexibility, elaboration, and creativity by prompting invention, strategic adaptation, and design refinement. This study shows the effectiveness of instructional simulation as a technique coupled with PJBL to foster creativity, understanding of concepts, and problem solving skills among learners in science education. The results suggest that these educational methods can improve student engagement and inspire innovative thinking.

Keywords
Simulation Videos; Problem-based Project Learning (PJBL); Creativity; Physics Education; Thermodynamics; Renewable Energy; Conceptual Understanding

Introduction

The study of physics has evolved alongside society's creative thinking and digital skills, especially in this period of value adding innovation in the 'disruptive' technology era. It integrates 21st century skills with other subjects, including creativity which allows students to cultivate scientific products. In teaching and learning processes in physics, creativity is gaining traction as one of the fundamental skills for 21st-century learners. As cited by Beghetto and Kaufman (2007), creativity is a cornerstone in resolving educational problems associated with enabling learners to be innovative and flexible in dynamic situations. Physics learning still relies on text and pieces in most Indonesian high schools, and this tends to impede the development of creativity for learners (Suyidno et al, 2020). Among the sociologically relevant as well as conceptually profound topics in a high school physics course, renewable energy is perhaps the most striking. This topic fosters scientific literacy and motivates students to participate in active problem-solving concerning environmental and technological issues. Although it is important, students have been reported to perceive the concepts of renewable energy as abstract and difficult to relate to their everyday life (Irfan et al., 2021), which results in a lack of interest and superficial understanding of the content. There is a need to develop new effective teaching methods to meet these needs.

Problem-based learning together with Project-based learning and simulation videos create powerful instructional aids. A case in point is a pedagogical model which places real-life projects at the center of a learner's work called PJBL. It is a constructivist educational strategy aimed at solving authentic real-world problems at the beginning of a learning unit, thereby serving as a primary motivation or propeller of learning outcomes (Taylor, 2017). Within PJBL, students participate in solving real-world problems, but they also have to plan and produce for specific real audiences, thereby refining their process and product evaluation skills (Tsybulsky & Muchnik-Rozanov, 2021). Furthermore, the collaborative nature of PJBL increases the level of participation, responsibility, and social interaction skills, which draws from the sociocultural standpoint that learning occurs as a result of interaction with other people (Shpeizer, 2019). Research indicates that PJBL can effectively develop students' higher-order thinking skills, including creativity, by engaging them in meaningful tasks that require exploration, design, and presentation (Bell, 2010).

In addition to PJBL, simulation videos in physics education provide a vivid depiction of phenomena, transforming complex ideas into stimulating and easy-to-understand material. Such videos contribute to learners' understanding and also encourage creativity and imagination. Rutten, van Joolingen, and van der Veen (2012) noted that simulations help learners understand and get interested in concepts taught in the computer-based science classes. With PhET Interactive Simulations, students can alter parameters, observe changes in energy, and experiment in a simulated environment (Wieman et al., 2010). The work of Yuliati et al. (2021) indicates that the combination of visual media and learning methodologies, such as constructivist PJBL, significantly enhances understanding and motivation towards science instruction. However, there is limited research that investigates the synergy of PJBL and simulation videos, especially in regards to students' creativity in developing rudimentary physics products. Thus, the purpose of this research is to assess the integration of simulation videos and PJBL to enhance creativity among physics education students in designing and developing functional and innovative teaching aids for physics that are relevant to real-world contexts. This study aims at Grade 10 learners in a senior high school in Indonesia to inform educators and curriculum designers about fostering creativity in teaching physics using integrated media instructional models.

Literature Review

Emerging concepts in creativity as well as PJBL (Problem-based Project Learning) approaches emphasize the need of integrating modern technologies into the educational curriculum. Simulation videos portray the most advanced and contemporary educational technologies as they modernize the student's approach towards education. The 21st century is often characterized by the advances in technology, which have had a profound effect on modern education. The new teaching methods, which utilizre this advanced technology, can slowly and step by step replace the traditional lectures, which have proved to foster passiveness and inertia in students. In addition to the application of new technologies, creativity is considered to be not only an important ability, but also a criterion for success in education, particularly in science classes where technological innovation is on the rise. Simulative videos serve as more than just a sophisticated educational apparatus; they are capable of enhancing the learner's experience. The integration of technology, especially simulation videos, coupled with student-centered approaches such as PJBL (Problem-based Project Learning), have been recognized as effective ways of enhancing creativity. As noted by Rutten et al. (2012), simulations as a computer application provides users with advanced manipulative activities that allow learners to interact with the system, alter parameters, carry out virtual tests, and see results immediately. This realism promotes a more practical approach to the learning of physics challenges students to comprehend rather than memorize. In this case, simulation videos help in the understanding of content, but moreover, they challenge the student to be adventurous and go beyond creative limits which lays the foundation for innovation.

When integrated within the framework of PJBL, simulation videos offer a synergistic pedagogical approach. PJBL shifts the learning process from passive knowledge reception to active inquiry, where students collaboratively solve authentic, real-life problems. As Hmelo-Silver (2004) explains, this student-centered model promotes deeper understanding, critical thinking, and knowledge construction. Within this context, simulation videos act as cognitive scaffolding supporting students' comprehension of complex problems while allowing them to visualize possible solutions and outcomes. Together, these methods foster an environment ripe for exploration, iteration, and innovation. Research supports the effectiveness of this combination. Aslan and Shiong (2023) demonstrated that students engaged in simulation-enhanced PJBL tasks exhibited significant gains not only in conceptual understanding but also in essential 21st-century skills such as creativity. Likewise, Tsybulsky and Muchnik-Rozanov (2021) found that PJBL, when supported by digital technologies, encouraged students to reflect on their creative processes, assess the quality of their ideas, and improve their problem-solving strategies. These findings suggest that such pedagogical integration empowers students to engage in metacognitive thinking and self-evaluation skills closely linked to creativity.

Furthermore, the use of simulations in physics learning is particularly beneficial in contexts where real-life experiments are too costly, dangerous, or logistically impractical (Smetana & Bell, 2012). In these situations, simulations can safely replicate phenomena, offering students the freedom to explore diverse hypotheses and test multiple problem-solving approaches. Mrani et al. (2020) argue that this flexibility nurtures curiosity and divergent thinking, both of which are key characteristics of creative learners. Creativity in physics education, therefore, extends beyond artistic interpretation. It encompasses the ability to generate novel ideas, approach problems from different angles, and construct meaningful representations or tools. Beghetto and Kaufman (2007) emphasize that creative thinking in science involves identifying problems, devising original solutions, and applying knowledge in practical contexts. Such competencies are critical in physics, where learners are often tasked with designing experiments, constructing models, or developing teaching aids.

Creating a learning environment that promotes creativity requires intentional effort. Cropley (2001) posits that creativity thrives in educational settings that value originality, tolerate ambiguity, and encourage experimentation. Kampylis and Valtanen (2010) further stress the importance of providing students with authentic tasks that integrate design, construction, and scientific reasoning. When simulation videos and PJBL are implemented cohesively, they align with these principles by supporting autonomy, engagement, and meaningful learning experiences. Moreover, motivation plays a central role in the development of creativity. According to Deci and Ryan (2000), intrinsic motivation driven by interest, enjoyment, and personal value is a strong predictor of creative behavior. Simulation-based PJBL environments are particularly effective in nurturing intrinsic motivation, as they offer students autonomy in problem-solving, relevance to real-world challenges, and opportunities for collaborative discovery. The interplay between cognitive and social dynamics in PJBL also deserves attention. Shpeizer (2019) explains that the collaborative nature of PJBL helps learners develop social creativity, where group members co-construct knowledge, share diverse perspectives, and negotiate meaning to reach common goals. This process fosters not only cognitive growth but also emotional resilience and adaptability traits necessary in today's complex learning environments. Similarly, Taylor (2017) asserts that students engaged in project-based learning take ownership of their learning journey, thereby enhancing their intrinsic drive to innovate.

The supporting rationale for combining simulation videos with PJBL also comes from constructivist and socio-constructivist learning theories. Vygotsky's (1978) zone of proximal development says students learn most efectively when they are guided through tasks that are slightly beyond their abilities, where a set of tools or peers aid them through scaffolding. Simulation videos serve as scaffolds by enabling learners through viewing and doing which supplements the talk and collaborative components of PJBL. In the context of teaching physics, students are sometimes expected to create simple physical models or teaching aids. This approach enhances students' creative capabilities. Students are motivated, not only to understand the fundamental physical concepts, but also to creatively use them in designing functional and meaningful products. This motivates STEM education which incorporates aspects of invention, creativity, and integration of interdisciplinary fields. The integration of PJBL with simulation videos is an effective and complete strategy for enhancing creativity in teaching Physics. The use of creativity in this combined approach creates an environment of cognitive and affective learning enhancing knowledge as well as fostering curiosity, reflection, collaboration, and invention. Such teaching innovations are necessary to prepare learners to address future technological and scientific challenges as educational systems across the globe focus on 21st century skills.

Methods

This study employed a descriptive qualitative approach to explore the creativity of physics education students in designing and producing simple physics products through the integration of simulation videos and Problem-Based Learning (PJBL). The research was conducted in a natural classroom setting involving a group of Grade 10 students participating in a project-based learning module. Data were collected through participant observation, semi-structured interviews, and documentation of student-created products, including written reports and physical prototypes. The study aimed at measuring creativity with Cropley's (2001) indicators on originality (uniqueness of ideas), fluency (quantity of ideas), flexibility (number of different viewpoints), and elaboration (amount of detail put towards the completion of the work). Thematic analysis was applied to highlight trends and patterns in the data which facilitated understanding interpretation relating concerning how the students devised, developed, and implemented their physics projects. This qualitative approach was selected to reflect the complexity, context, and processual nature of creativity which is not easily quantified (Creswell & Poth, 2018).

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Data Analysis

The data in this study were analyzed using thematic analysis, a qualitative method for identifying, analyzing, and reporting patterns (themes) within the data. This method was chosen because it allows for a detailed, interpretive exploration of student creativity in the process of designing and producing simple physics products. Data were obtained from three sources: (1) participant observation during class activities, (2) semi-structured interviews with students about their creative process, and (3) documentation in the form of students' written reports, sketches, and physical prototypes. All data were coded manually and categorized into themes related to creativity indicators.

The analysis focused on four key dimensions of creativity based on the theoretical framework of Cropley (2001):

1. Originality: assessed through the uniqueness and novelty of the ideas presented in the students' product designs.
2. Fluency: evaluated by the number and diversity of ideas generated during the planning and problem-solving phases.
3. Flexibility: observed in the students' ability to shift strategies or change perspectives in overcoming design or conceptual challenges.
4. Elaboration: examined through the completeness, refinement, and detailing of the final product, including visual, functional, and explanatory aspects.

Each student's project was assessed holistically by triangulating the observational data, student reflections during interviews, and the physical outcomes of their work. Themes emerging from the data included the influence of simulation videos on idea generation, the role of collaboration in expanding perspectives, and the iterative nature of students' design processes. Thematic interpretation allowed for a rich understanding of how creativity unfolded in a physics education context mediated by PJBL and simulation technology.

Results

The findings of this study indicate that the integration of simulation videos and Problem-Based Learning (PJBL) significantly enhanced students' creativity in the production of simple physics teaching aids. The data analysis, guided by the four dimensions of creativity proposed by Cropley (2001) originality, fluency, flexibility, and elaboration generated several key thematic outcomes, all of which are visually supported by the media artifacts available at the following link: https://drive.google.com/drive/folders/18yNWGMGG8mdnLN6l6wvEsc22WKtSMq36?usp=sharing. This Google Drive folder contains curated documentation of students' final thermodynamics projects and demonstrations. These materials vividly capture their creative processes, problem-solving strategies, and hands-on experimentation. The data analysis, guided by the four dimensions of creativity proposed by Cropley (2001)n originality, fluency, flexibility, and elaboration generated several key thematic outcomes:

1. Originality

The dimension of originality was prominently demonstrated in students' ability to generate unique, innovative, and contextually relevant designs for physics learning media. Based on classroom observations, analyses of students' water-powered toy car prototypes, and reviews of their written project reports, it was evident that many groups created instructional tools characterized by a high degree of novelty and creative interpretations of thermodynamic concepts. For instance, one group successfully designed a water-powered toy car using a simple mechanism involving a syringe and a plastic bottle to convert water pressure into kinetic energy. Another group ingeniously repurposed a used shampoo bottle and a bicycle valve system to regulate water propulsion demonstrating not only an original application of thermodynamic principles but also a strong commitment to sustainability through the use of recyclable materials. Other simple yet inventive projects included a steamboat, a popcorn machine, and a candle-powered convection turbine. Each of these exemplified students' efforts to visualize and materialize heat and energy transfer concepts through hands-on experimentation and the creative use of everyday objects. These products were not mere adaptations of existing models; rather, they emerged from students' interpretations of the first and second laws of thermodynamics and their engagement with the concept of renewable energy.

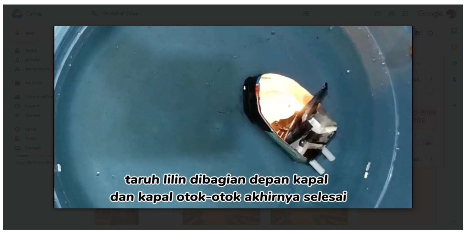

Figure 1. Steamship Otok – Otok

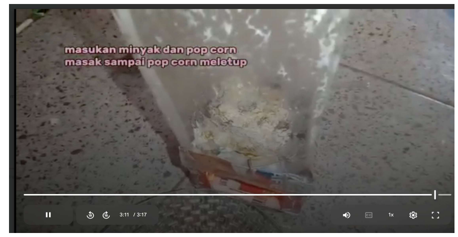

Figure 2. Popcorn Machine

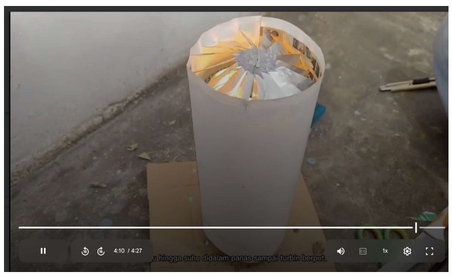

Figure 3. Candle Powered Convection Turbine

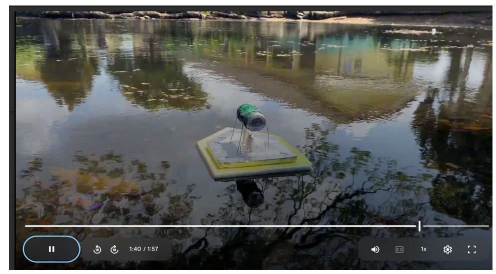

Figure 4. Steamship

Examples of these thermodynamic products are shown in *Figure 1: Steamship Otok-Otok*, *Figure 2: Popcorn Machine*, *Figure 3: Candle-Powered Convection Turbine*, and *Figure 4: Steamship*. These student-created devices illustrate practical applications of core thermodynamic principles such as heat transfer, energy conversion, and system efficiency. The *Otok-Otok* steamship and the larger steamship model demonstrate how vapor pressure from boiling water can be used to generate mechanical motion. The *Popcorn Machine* embodies the transformation of thermal energy into both mechanical motion and the physical expansion of kernels, while the *Candle-Powered Convection Turbine* exemplifies how heated air can create rotational movement through convection currents. All these projects were built using recycled and low-cost materials, underscoring students' creativity, resourcefulness, and understanding of physics concepts.

Semi-structured interviews revealed that students were motivated to avoid conventional approaches and deliberately pursued alternative designs. Many participants stated that simulation videos played a pivotal role in inspiring their ideas by visualizing the transformation of energy particularly in demonstrating how water pressure could serve as a renewable propulsion source for small-scale vehicles. This visual exposure helped students reimagine abstract concepts such as energy conversion, system efficiency, and heat dissipation, translating them into tangible and functional designs. These findings are consistent with previous research suggesting that visual-interactive learning tools promote divergent thinking and creative problem-solving in science education (Rutten, van Joolingen, & van der Veen, 2012; Sadaghiani, 2012). Furthermore, they align with Cropley's (2001) definition of originality as the production of ideas that are both novel and contextually appropriate. The learning environment, which encouraged exploration, autonomy, and authentic problem-solving within the context of renewable energy projects, effectively fostered originality in students' creative outputs (Tsybulsky & Muchnik-Rozanov, 2021).

2. Fluency

The dimension of fluency was reflected in the students' ability to generate a diverse range of ideas and possible design solutions during the brainstorming and problem-solving phases of their water-powered toy car projects. Based on classroom observations, it was noted that students actively explored multiple alternatives in both the selection of materials and the mechanisms for converting water pressure into motion, demonstrating the capacity for ideational fluency as defined by Cropley (2001). During the early stages of project planning, students proposed various propulsion concepts, including the use of syringes, balloon pressure systems, modified plastic bottles, and even elastic-powered auxiliary components to enhance the vehicle's speed and stability. Some groups experimented with different nozzle

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designs and water discharge angles to optimize propulsion force based on thermodynamic efficiency principles, particularly related to energy transfer and fluid dynamics.

Semi-structured interview data further indicated that simulation videos contributed significantly to expanding students' idea generation. The simulations presented multiple visual scenarios of energy transformation such as the conversion of potential energy in pressurized water to kinetic energy prompting students to discuss and test a broader range of possibilities. Students reported that the videos inspired them to combine features from different models or innovate new designs by modifying concepts they had never considered before. This finding aligns with existing literature on the relationship between simulation-based instruction and increased idea fluency in science education. Rutten, vanJoolingen, and van der Veen (2012) emphasized that computer simulations enhance students' ability to visualize complex systems and stimulate diverse responses in problem-solving contexts. Likewise, Tsybulsky and Muchnik-Rozanov (2021) highlighted the effectiveness of project-based learning environments in promoting ideational fluency through interdisciplinary and exploratory tasks. In this study, the combination of PJBL and simulation videos proved effective in encouraging students to produce a wide variety of ideas, test multiple prototypes, and iteratively refine their designs to achieve the most effective water-powered car based on thermodynamic concepts.

3. Flexibility

The dimension of flexibility was observed in students' capacity to shift strategies, modify designs, and adopt alternative perspectives when confronted with technical challenges or limitations during the creation of their water-powered toy cars. This adaptability in problem-solving reflects Cropley's (2001) concept of creative flexibility, which involves the ability to approach problems from different angles and to change strategies when necessary. Classroom observations showed that during the prototyping phase, several student groups encountered unforeseen obstacles, such as water leakage, insufficient propulsion force, or instability in the vehicle's structure. Rather than persisting with ineffective designs, students demonstrated a willingness to reconsider and adjust their approaches. For example, one group that initially planned to use a single syringe propulsion system switched to a dual-syringe model after discovering that a single system failed to generate enough pressure. Another group replaced rigid plastic wheels with bottle cap wheels filled with clay to improve traction and stability, applying basic thermodynamic considerations regarding energy efficiency and system optimization.

Semi-structured interviews reinforced these observations, as students described how simulation videos and collaborative discussions enabled them to envision multiple possible modifications when faced with difficulties. Many students reported that the visualizations of different energy conversion systems in the simulations encouraged them to try alternative nozzle designs, vary the water injection angles, or adjust the car's mass distribution to improve propulsion efficiency directly applying concepts from the first and second laws of thermodynamics related to energy transfer, work output, and system equilibrium. These findings align with prior research by Tsybulsky and Muchnik-Rozanov (2021), who identified that project-based learning fosters flexibility by exposing students to open-ended tasks that require iterative design and continuous refinement. Likewise, Rutten et al. (2012) found that simulation-based instruction enhances students' cognitive flexibility by providing multiple representations of scientific phenomena and encouraging exploratory learning. In this study, the combination of PJBL and simulation videos not only facilitated students' understanding of thermodynamic principles but also nurtured their ability to flexibly adapt and optimize their designs in response to real-time challenges.

4. Elaboration

The dimension of elaboration was demonstrated in the students' ability to develop their initial ideas into well-detailed, refined, and functionally complete water-powered toy car prototypes. According to Cropley (2001), elaboration involves adding details, improving concepts, and enhancing the completeness of creative products a quality clearly evident in both the students' physical models and their accompanying reports. Classroom observations showed that after initial trials, most groups continuously refined their designs by adjusting component placements, improving water propulsion systems, and optimizing the overall structure of their vehicles. Some groups modified the water tank shape to increase pressure capacity, while others created adjustable nozzle attachments to regulate water discharge angles, directly applying thermodynamic concepts such as pressure-volume work and energy transfer efficiency.

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In addition to mechanical improvements, students also elaborated on the visual and instructional aspects of their projects. Several groups decorated their vehicles with clear labels indicating the points of energy conversion and included explanatory posters illustrating how the first and second laws of thermodynamics operated within their toy cars from the potential energy in compressed water to the kinetic energy propelling the vehicle forward, and the inevitable dissipation of energy as heat due to friction. Data from semi-structured interviews supported these findings, as students explained how both simulation videos and the PJBL process helped them recognize areas needing improvement. The simulations, in particular, provided reference models of energy transformation systems, inspiring students to incorporate additional features like pressure gauges, adjustable propulsion angles, or modular components that could be easily replaced or modified for future experiments.

These results resonate with prior research indicating that project-based learning environments, combined with visual simulation tools, encourage students not only to generate ideas but also to develop those ideas into sophisticated, coherent, and functional products (Tsybulsky & Muchnik-Rozanov, 2021; Rutten et al., 2012). The iterative nature of PJBL enabled students to revisit and refine their projects repeatedly, while simulation videos expanded their conceptual understanding and attention to technical detail. In conclusion, the integration of PJBL and simulation technology successfully promoted elaboration in students' creative processes, resulting in the production of water-powered toy cars that were not only technically effective but also educationally valuable as physics learning media on thermodynamics and renewable energy.

Discussions

Simulation videos were shown to be particularly influential in stimulating students' creativity. These visual tools provided dynamic representations of abstract scientific principles such as energy conversion, pressure-volume work, and system efficiency in a way that traditional textbooks or static diagrams could not. The ability to see these principles in action allowed students to conceptualize and experiment with novel designs for their water-powered vehicles, moving beyond conventional solutions and integrating interdisciplinary ideas. This finding aligns with previous research indicating that interactive simulations can trigger divergent thinking and enhance conceptual understanding in science education (Rutten, van Joolingen, & van der Veen, 2012; Sadaghiani, 2012).

Furthermore, the use of simulation videos facilitated a deeper understanding of the laws of thermodynamics, as students were able to visualize and manipulate the conversion of energy in a real-world context. For example, through the simulation, students could experiment with adjusting variables like water pressure and nozzle angle, immediately observing the effects on the toy car's speed and efficiency. This hands-on, visual approach provided students with a more concrete understanding of energy transfer and system dynamics, which directly influenced the creativity and functionality of their final projects.

Moreover, simulation videos facilitated a deeper understanding of thermodynamic laws by allowing students to visualize and manipulate energy conversion within real-world contexts. For instance, students could virtually adjust variables like water pressure and nozzle angle, and instantly observe their effects on vehicle speed and propulsion efficiency. This hands-on, visual approach made abstract processes such as energy transfer and system dynamics more concrete and relatable, directly influencing the creativity and functionality of their final product designs. These learning experiences culminated in presentation and discussion sessions following the simulation phase, as illustrated in Figure 5 (Presentation and Discussion after Simulation) and Figure 6 (Presentation and Discussion after Simulation). During these sessions, students shared their initial prototypes, received feedback from peers and instructors, and refined their conceptual understanding based on what they observed and learned through simulation.

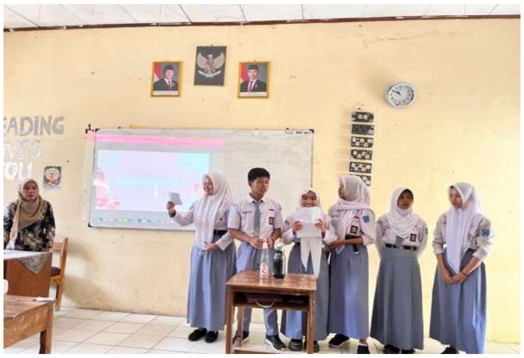

Figure 5. Presentation and discussion 1

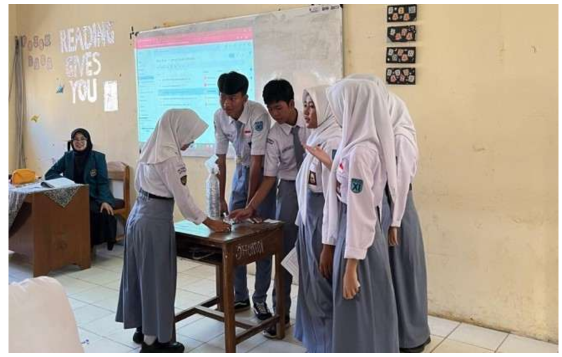

Figure 6. Presentation and discussion 2

PJBL, on the other hand, provided a structured yet flexible environment where students could engage in authentic problem-solving tasks. The open-ended nature of the project allowed students to explore multiple design options, test hypotheses, and iterate on their designs. This process was critical in promoting flexibility and elaboration, as students were constantly revising their prototypes in response to challenges, such as optimizing propulsion efficiency or overcoming technical limitations like water leakage.

Additionally, the collaborative aspect of PJBL encouraged students to exchange ideas and gain different perspectives, which contributed to fluency in generating a wide variety of design solutions. The group dynamics not only supported brainstorming but also allowed students to combine ideas, refine concepts, and create more sophisticated prototypes. This is consistent with findings from Tsybulsky and Muchnik-Rozanov (2021), who emphasize the importance of collaborative learning in fostering creativity in STEM education, particularly when students are tasked with solving complex, interdisciplinary problems.

This study demonstrates the value of integrating simulation technology and PJBL into science education, particularly in topics related to energy and thermodynamics. By encouraging students to apply theoretical knowledge to practical projects, educators can enhance students' understanding of complex scientific concepts while also promoting creativity and problem-solving skills. The integration of renewable energy principles into the project also highlights the importance of teaching students about sustainable technologies, fostering an awareness of how scientific knowledge can be used to address real-world challenges. Furthermore, the study suggests that student engagement and autonomy are crucial for fostering creativity. When students are given the freedom to explore, experiment, and refine their ideas, they are more likely to produce innovative and functional designs. As such, educators should consider creating learning environments that emphasize exploration, hands-on experimentation, and real-world problem-solving to maximize student creativity and learning outcomes.

Conclusion

This study highlights the significant role of simulation videos and Problem-Based Learning (PJBL) in enhancing students' creativity in designing simple physics teaching aids, specifically water-powered toy cars, while exploring the principles of thermodynamics and renewable energy. The integration of these educational tools effectively fostered creativity across the four key dimensions: originality, fluency, flexibility, and elaboration. Students demonstrated originality by developing novel solutions that were not based on pre-existing models, incorporating interdisciplinary ideas, and applying thermodynamic principles to optimize energy conversion. Fluency was observed in the wide variety of ideas and design modifications that students generated, especially in response to challenges faced during the design and prototyping phases. The flexibility exhibited by students in adapting their designs and modifying their approaches to overcome obstacles further underscored the success of PJBL in fostering creative problem-solving. Lastly, the elaboration of their projects was evident in the refinement and detailing of their prototypes, where students improved not only the functionality of their designs but also the visual and instructional aspects to communicate scientific concepts more effectively.

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The use of simulation videos played a crucial role in enhancing students' understanding of abstract scientific principles by providing a dynamic, visual representation of energy transformations, helping them to reimagine and test new ideas. Additionally, PJBL's open-ended, collaborative nature enabled students to engage in iterative design processes, enhancing their ability to experiment and refine their ideas, leading to more sophisticated and functional prototypes. Overall, the findings suggest that combining simulation-based instruction with project-based learning offers a highly effective approach to fostering creativity and deepening students' understanding of scientific principles. These results have important implications for science education, particularly in the context of teaching complex topics like thermodynamics and renewable energy. Educators are encouraged to incorporate simulation tools and PJBL strategies into their teaching to promote creativity, critical thinking, and practical application of theoretical knowledge in real-world context

Limitations and Future Studies

Although this study provides valuable insights into the role of simulation videos and Problem-Based Learning (PJBL) in fostering creativity in the context of physics education, there are several limitations that should be considered when interpreting the results.

One of the primary limitations of this study is the relatively small sample size, which may limit the generalizability of the findings. The study was conducted with a limited number of students from a single educational institution, which may not represent the diversity of students across different schools or regions. Future studies with larger and more diverse samples could provide a broader understanding of how simulation videos and PJBL influence creativity in various educational contexts. The focus of this study was on thermodynamics and renewable energy, with students designing water- powered toy cars. While these topics are highly relevant to current scientific and environmental issues, the results may not be applicable to other areas of physics or different subject matters. It would be beneficial to investigate how the integration of simulation videos and PJBL impacts creativity in other branches of science, such as electricity, magnetism, or mechanics. The study was conducted over a relatively short period of time, which may have constrained students' ability to fully explore their ideas and refine their projects. The duration of the learning experience may not have been long enough to observe deeper, more sustained changes in creativity or conceptual understanding. Long- term studies would be valuable to examine whether the benefits of simulation and PJBL persist over time and how they influence students' development in the long run. While the study focused on student creativity, it is important to acknowledge the potential influence of the teacher and classroom environment on the outcomes. Teachers' teaching styles, guidance, and facilitation of the PJBL process may have influenced how students engaged with the project and the creativity they demonstrated. Further research could explore how different teaching methods and classroom dynamics affect the creative outcomes of students in project-based learning contexts.

Future research could explore the long-term effects of using simulation videos and PJBL on student creativity and learning outcomes. Longitudinal studies could provide insights into how these educational approaches influence students' abilities to think critically, solve problems, and innovate over time. Additionally, tracking students' academic performance in subsequent courses or in real-world scenarios would help assess the long- term impact on their STEM skills. Expanding the sample size and including students from various educational backgrounds, regions, and schools would increase the generalizability of the findings. Furthermore, conducting the study across different educational systems or cultures could provide a better understanding of how these teaching methods work in diverse settings and with different student populations. While this study focused on thermodynamics and renewable energy, future research could examine the application of simulation videos and PJBL in other areas of physics or even in other STEM disciplines. For instance, studies could explore how these methods impact creativity in subjects such as electromagnetism, chemical reactions, or environmental science, where visualizing abstract concepts is also crucial. Future studies could investigate the role of teacher professional development in effectively implementing simulation-based learning and PJBL. Training teachers to use simulation tools and design PJBL activities that foster creativity could enhance the overall effectiveness of these methods in promoting student innovation. Understanding how teachers can best facilitate creative learning experiences could improve outcomes in STEM education. It would be beneficial to compare the effects of simulation-based PJBL with traditional teaching methods or other innovative pedagogical approaches. For example, a study that contrasts simulation-

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based learning with hands-on experiments or inquiry-based learning could provide valuable insights into which methods are most effective for fostering creativity and conceptual understanding in students.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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