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Development of Problem-Based Physics E-Book on The Topics of Work And Energy to Improve Students' Conceptual Understanding and Digital Literacy

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Abstract: This study aims to develop an electronic book (e-book) based on the Problem-Based Learning (PBL) approach to enhance students' conceptual understanding and digital literacy on the topic of work and energy. Responding to the growing demand for interactive and student-centered learning media in physics education, the e-book is designed to serve as a learning resource that fosters engagement in problem-solving and critical thinking. The research adopts the ADDIE development model, comprising Analysis, Design, Development, Implementation, and Evaluation, and applies a quantitative approach using a one-group pretest-posttest design. Participants in this study were tenth-grade students from State Senior High School 9, Yogyakarta. Data were collected through the use of the developed e-book, conceptual understanding tests, digital literacy questionnaires, and student response surveys. Validators rated the e-book as “highly valid” and suitable for use. The implementation results showed a significant improvement in students' conceptual understanding, with an N-gain score of 0.71, which falls into the high category. Additionally, there was an improvement in digital literacy, with an N-gain score of 0.66, which also falls into the high category. The effectiveness of this e-book was also tested using a T-test and showed significant improvements before and after learning for both variables. Additionally, students responded positively, finding the e-book engaging, easy to access, and beneficial in supporting their learning process. These preliminary findings indicate that the PBL-based e-book has the potential to be an effective learning tool for high school physics education.

Keywords: e-book, problem-based learning, work and energy, conceptual understanding, digital literacy.

▪ INTRODUCTION

Physics is one of the most important basic science subjects. This is because physics is not just a rote science, but a scientific discipline that aims to educate students to be able to think logically and critically to solve problems, both problems in physics and everyday life, through a deep understanding of concepts. In general, physics is considered one of the most challenging subjects for students, as many students have difficulty understanding abstract ideas (Musengimana et al., 2025), in line with the many research findings stating that many students experience misconceptions in understanding physics concepts (Bitzenbauer, 2021). The challenge in physics education lies not only in conceptual understanding but also in students' ability to apply concepts in real-world contexts. This may be because students find it easier to understand the material when they combine theory with hands-on applications (Shishigu et al., 2018). In addition, another factor that contributes to the prevalence of misconceptions is the use of inappropriate teaching methods (Xie et al., 2025).

In the context of implementing the Indonesian “Merdeka” Curriculum, active and student-centered learning approaches are strongly emphasized. In line with Adamczyk et al. (2025) research, student-centered learning will make students more active and more likely to ask questions and argue. The choice of learning model is another important

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component that affects the process of learning physics. The learning model that is suitable for implementation in the “Merdeka” Curriculum is the problem-based learning model. In the implementation of the independent curriculum, teachers have a significant role. Teachers must comprehend the idea and be proficient in its application during the learning process in order to serve as facilitators.

Consequently, PBL emerges as a highly appropriate instructional model. PBL encourages students to develop critical thinking skills through real-world problem-solving, thereby fostering deeper conceptual understanding. Students' difficulties in applying physics concepts to the real world are highlighted in research by Gustafsson et al. (2015). Various international studies have proven that PBL significantly affects students' academic performance, meaning that the PBL model can help improve students' mastery of concepts (Sagatbek et al., 2024). This is supported by Nicholus et al. (2023), which states that PBL is effective in various aspects of physics learning.

Problem-Based Learning (PBL) has been recognized as a development of active learning and a learner-centered learning approach. Active learning is considered more effective than traditional learning (Marušić & Dragojević, 2020). Therefore, the PBL model uses problems to trigger more active learning. These problems can originate from real-world issues or complex simulated problems. The methods used by teachers to teach and learn are not very effective and might lead to misunderstandings among students, which is why this teaching paradigm is not often used in practice. This is certainly regrettable, as according to Li & Singh (2018), PBL-based learning is considered more effective than conventional learning. However, although PBL has been widely studied in different subjects, research on its integration into the topic of Work and Energy in physics learning remains limited, particularly in developing countries. Additionally, the use of digital learning media in PBL, such as interactive e-books, is still relatively new and lacks sufficient empirical exploration in the context of secondary physics education.

One of the topics most frequently associated with misconceptions is Work and Energy, known for its counterintuitive concepts that are nevertheless highly relevant to everyday life. According to Haji et al. (2023) which states that one of the topics in physics that are considered difficult is work and energy, so students need to improve their mastery of the concepts in this material. Currently, students' mastery of concepts is still in the low category. Mastery of concepts is not only about understanding, but also being able to apply the concepts presented and solve problems related to those concepts. Conceptual mastery can be used as a benchmark to measure how well students understand and master the material that has been taught. One approach is to identify physics concepts (Weihs et al., 2025).

On the other hand, digital literacy has become an essential 21st-century skill in science education. Research by Nugrahani et al. (2023) found that mastery of concepts is closely related to digital literacy skills. The study mentioned that students with higher digital literacy skills tend to have a more comprehensive understanding of concepts and key ideas. It encompasses not only the ability to access digital information but also the capacity to critically evaluate, interpret, and apply such information effectively to solve problems (Ng, 2012). In physics learning, students with higher digital literacy are generally better equipped to understand simulations, analyze data, and connect abstract theories to real-world phenomena. This is supported by a statement stating that in physics learning, digital literacy skills are fundamental (Mears et al., 2025). However, because they are not exposed to digital media enough and receive little assistance from their teachers, many students still exhibit low levels of digital literacy. Therefore, research is needed that comprehensively examines the concept of reading literacy skills, especially in the context of the digital age (Lahnwong, 2019). This situation highlights the need for the development of digital-based learning media, such as PBL-integrated e-books, that can simultaneously support the improvement of both conceptual understanding and digital literacy.

In this situation, interactive learning media are necessary to support the learning process. According to Nenggala et al. (2024), the use of digital-based learning media will make learning more flexible and interactive. Thus, the development of learning media is one solution to this problem. Teachers must create learning media that attracts students' interest. Learning media facilitates the learning process by acting as a conductor, mediator, and message carrier. Students will undoubtedly become more interested in taking part in the learning process if interactive digital learning materials are used. This is in line with research stating that digital-based learning will help students understand and master concepts in learning (Samsudin et al., 2020). One type of learning media that can support the use of digital-based technology commonly used in learning is e-books. E-books are books that have been adapted into electronic form, and to read them, readers need devices such as computers, laptops, smartphones, or other electronic devices. E-books will be more appealing to students. With their potential, e-books can now be one of the media used to support the learning process that can be used anywhere.

Research on this topic has been conducted by several researchers previously. One of them is the research conducted by Watin et al. (2023). The focus of this research is to produce a product that is feasible, effective, and practical for use in physics learning, especially on the topic of mechanical waves. In addition, the purpose of this research is to improve students' understanding of the material. This research is a development study using a 4D research design. However, the dissemination phase was limited to only one class. This is supported by the statement that the sample taken in this study was only one class, consisting of 26 students. Furthermore, this study does not mention the learning model used in the research. Another limitation of this study is that the features used are limited to core competencies, standard competencies, materials, and quizzes, without any learning activities.

Another study conducted by Fiedler et al. (2023) discusses the difficulty of students in understanding the concept of energy, especially potential energy. Fiedler et al. (2023) propose a solution by emphasizing conceptual understanding in energy learning. This study used mixed-methods by comparing two groups of 7th-grade students (N=67), where one group learned energy with conceptual learning and the control group learned without emphasizing conceptual understanding. The results showed that students taught using the conceptual field performed significantly better on the energy test, developed a more connected knowledge network, and mentioned the idea of energy conservation more often. Overall, this article concludes that the introduction of terrain concepts can help students' deeper and more sustainable conceptual understanding of energy.

In addition, several international studies have also revealed that combining PBL with digital technology yields positive results in science education. However, there is still a lack of research examining the specific effectiveness of PBL-based e-books in teaching the topic of Work and Energy (Hidayati et al., 2024). Thus, this study aims to address this gap by developing and evaluating a PBL-based e-book intended to improve students' conceptual understanding and digital literacy in high school physics. This aligns with research by Notaros (2021), which states that the PBL learning model can improve students' conceptual understanding.

Based on the background described above, this study aims to test the validity and feasibility of the PBL-based e-book developed on Work and Energy, investigate its impact on students' conceptual understanding, and explore its influence on improving students' digital literacy. This research contributes to the development of existing knowledge with a specific focus on the integration of PBL and interactive e-books in the challenging topic of Work and Energy, while addressing the crucial 21st-century skill of digital literacy. The findings of this research are expected to provide valuable insights for educators to package physics learning in an innovative, effective, and beneficial way for students.

▪ METHOD

Participants

The population in this study consisted of all tenth-grade students at State Senior High School 9, Yogyakarta. The sample selected was class X5, with a total of 36 students. The X5 class was chosen using purposive sampling. Purposive sampling was employed to target people who possessed particular traits that would offer a more profound understanding of the research topic (Ames et al., 2019). Based on academic and demographic characteristics considered to be moderately representative, the class was selected due to its balanced academic performance, demographic diversity, and sufficient digital infrastructure, which made it suitable for testing the feasibility of digital learning media such as e-books. Therefore, this study will provide new and deeper insights into the effectiveness of the learning application.

Research Design and Procedure

This study used a Research and Development (R&D) method. According to Slamet (2022), R&D is a research approach used to develop a product and evaluate its effectiveness. The development model used was the ADDIE model, consisting of five stages: Analyze, Design, Develop, Implement, and Evaluate (Branch, 2009). The ADDIE model's structured and adaptable methodology, which emphasizes ongoing assessment, makes it popular. This methodology guarantees that the intended learning application is more efficient, pertinent to the requirements of the students, and able to enhance the caliber of the educational process (Barokah & Sutikno, 2025).

The initial Analysis stage involved a thorough investigation to identify learning problems and inform the development of the e-book. In order to determine the current learning conditions, physics teachers at SMA Negeri 9 Yogyakarta were observed and interviewed as part of a thorough needs analysis. It was discovered that the teaching approach remained mostly teacher-centered and that digital media was not being used in the classroom to its full potential. To find pertinent ideas from the Work and Energy issue that will make up the main learning content, a curriculum analysis was also conducted. Additionally, a study of student characteristics showed that many students thought physics was a challenging and boring subject, which made them less interested in learning it. The importance of creating creative and engaging digital learning materials was highlighted by these early results.

After the analysis was completed, the design phase began, concentrating on the product's blueprint and related tools. An e-book on the subject of Work and Energy that was built on Problem-Based Learning (PBL) was carefully created. Concurrently, auxiliary tools were created, including instructional modules that were customized to fit the PBL syntax, digital literacy questionnaires, student response questionnaires, and pretest-posttest questions to gauge conceptual knowledge. The e-book's pedagogical design included features that explicitly corresponded to the five main phases of PBL: problem orientation, learning organization, autonomous investigation, group presentations and discussion, and evaluation.

The next phase is the development phase. During the development stage, the first draft of the e-book and its accompanying materials were created and verified. The product's quality and implementation readiness were guaranteed by this important phase. One content specialist and two seasoned physics professors rigorously validated the e-book and its tools. The content appropriateness, pedagogical consistency, and general alignment with the PBL syntax were all carefully evaluated by these validators. The e-book itself was created in an interactive PDF format by utilizing Canva Education. After that, the completed e-book in PDF format is uploaded to the Heyzine website to obtain an e-book link for convenient access.

A restricted trial of the created e-book with the chosen sample class X5 followed in the Implementation step. Over three weeks, there were six separate learning sessions, each spanning two 45-minute sessions. Each lesson followed the PBL syntax: (1) Problem orientation using real-life case studies embedded in the e-book, (2) Learning organization facilitated by interactive worksheets, (3) Independent investigation supported by access to PhET simulations, (4) Group presentations and discussion, and (5) Reflection and evaluation. The teacher acted as a facilitator, guiding the discussion and providing formative feedback. The defined PBL syntax wasstrictly adhered to during these sessions.

In order to aid in problem orientation, students were initially exposed to real-life case studies that were included in the e-book. Interactive worksheets served as a guide for learning organization, and direct access to PhET simulations encouraged autonomous research. Group conversations and presentations promoted collaborative learning, which culminated in a phase of reflection and assessment. The teacher took on the role of a facilitator during this process, directing conversations, elaborating on ideas, and giving pupils formative comments.

Lastly, a formative evaluation of the created product was the primary focus of the Evaluate stage. Since the implementation was carried out as a limited experiment with a single group, evaluating the e-book's initial viability and efficacy was the main goal rather than extrapolating results. In order to pinpoint areas that can benefit from improvement, this step was especially designed to collect user input. To determine the e-book's usefulness and general acceptance as a teaching tool, data on students' reactions to it were methodically gathered and examined. The knowledge gathered from this assessment stage was essential for guiding subsequent enhancements and guaranteeing the product's pedagogical soundness prior to thinking about wider use.

Instrument

The test instrument, consisting of pretest and posttest questions, was used to evaluate students' improvement in understanding concepts related to Work and Energy. This instrument contained 10 multiple-choice questions carefully formulated by adapting content from standard physics textbooks and problems inspired by PISA-style questions, which emphasize the application of concepts in real-world contexts. Each question item was designed to test a specific understanding of core concepts in the topic of Work and Energy, in accordance with the question matrix that has been developed.

The given questions assessed students' ability not only in calculating physical quantities but also in interpreting phenomena, analyzing relationships between variables, and applying physics principles in diverse situations. For example, Question No. 1 tests the understanding of work and energy concepts (C1 - Remembering), while Questions No. 2 and 9 measure the ability to analyze positive and negative work and apply the law of conservation of mechanical energy to specific phenomena (C4 - Analyzing). Furthermore, Question No. 4 focuses on applying work and energy concepts in everyday life to determine potential and kinetic energy (C3 - Applying). Finally, Question No. 10 also falls within the C4 (Analyzing) domain, requiring students to critique a phenomenon to find velocity using the law of conservation of mechanical energy. These questions have been validated using Aiken's V formula, with a threshold value of ≥ 0.8 indicating high validity and suitability of the items to measure the intended construct.

This digital literacy questionnaire, comprising 20 Likert-scale items, is based on Ng (2012) digital literacy indicators, covering six key aspects. Information literacy assesses students' ability to search for, evaluate the credibility of, and manage information from various online sources and e-books, including distinguishing valid from invalid information. Communication literacy evaluates their effective use of digital tools for communication within e-books or interactive learning materials. Collaboration literacy examines their capacity to work and share information with peers or teachers via digital platforms integrated with e-books. Creativity literacy focuses on their use of digital tools to create or modify content, such as filling interactive responses or making digital notes within e-books. Evaluation literacy measures their critical ability to assess information and digital tools, including the effectiveness of simulations or the reliability of external e-book sources. Lastly, security literacy gauges their understanding of safe digital practices, like protecting personal data and privacy when interacting with e-book simulations or external links. All survey questions specifically refer to students' experiences with e-books and related digital resources to comprehensively capture their digital literacy competencies.

The student response questionnaire is a non-test instrument designed to gather qualitative and quantitative feedback on students' perceptions and experiences with e-books, ultimately assessing their practicality and usefulness in the learning process. This questionnaire measured several crucial aspects determining e-book acceptance, specifically focusing on content, design, and language. The response to e-book content evaluated the clarity of material, accuracy of concepts, relevance of examples to everyday life, and depth of explanations, asking students if the content aids their understanding of Work and Energy concepts. The response to e-book design assesses visual aesthetics, layout, image, and simulation quality (including integrated PhET simulations), and the functionality of interactive features like answer input fields, hyperlinks, and self-assessment rubrics. Lastly, the response to language used examines the clarity of instructional language, ease of understanding physics terms, and the use of straightforward, unambiguous language. Feedback from this survey is invaluable for formative evaluation and product refinement, providing direct user insights into their experience with the developed learning media.

Validation instruments, expert validation sheets were used to assess the quality of content and appearance. The instrument validity sheet was used to determine the validity of an instrument before it was used in collecting data. In addition, this validity sheet also contained suggestions and input from the validator, which can be used as a reference in improving the instrument. The research instruments that were assessed for validity were the instruments used in the study in the form of pretest and posttest questionnaires, and digital literacy questionnaires. The validity sheet that has been filled in by the validator will then be statistically analyzed to determine the validity of the data collection instrument. Instruments that are declared valid can be used to collect research data.

Data Analysis

Instrument feasibility was analyzed using the Ideal Standard Deviation (SBi) method. This approach was chosen to classify instrument quality based on the distribution of validator scores. Although more commonly used methods, such as Cronbach's Alpha and factor analysis, offer comprehensive reliability assessment, SBi was selected for its practical utility in small-scale, initial validations. The validity of the test and questionnaires was examined using Aiken's V formula, where values ≥ 0.8 indicated strong validity. To assess improvements in conceptual understanding and digital literacy, data were analyzed using the Normalized Gain (N-Gain) formula. The criteria for improvement in the measured variables will be classified with reference to the following:

Table 3. Standard gain value criteria

Gain Value	Criteria
$0.65 \leq g$	High
$0.45 \leq g < 0.65$	Upper Medium
$0.25 \leq g < 0.45$	Lower Medium
$g < 0.25$	Low

(Sutopo & Waldrip, 2014)

In addition to analyzing improvements using n-gain, in this study, the pretest and posttest results were also analyzed for effectiveness using a T-test with the assistance of SPSS Statistics 25 software. If the significance result shows a value below 0.05, it can be said that there is a significant difference between before and after learning. Conversely, if the significance value is greater than 0.05, it can be said that there is no significant difference between before and after learning.

The research instruments were analyzed using several different methods. Student response questionnaires on the practicality and acceptability of e-books was analyzed using Ideal Standard Deviation (SBi) analysis. This method is used to classify the quality of a product or instrument based on the average score obtained from student responses or expert ratings. SBi analysis involves calculating the ideal mean and ideal standard deviation of the maximum possible score range (e.g., Likert scale). The results of the analysis were then categorized (e.g., Excellent, Good, Fair, Deficient) based on predetermined intervals relative to these ideal values. This provides a quantitative measure of the feasibility and acceptability of the product or instrument developed. In this study, SBi analysis was used for expert validation of PBL-based e-books, teaching modules, and student response questionnaires, as well as to analyze student responses to the practicality of e-books.

For pretest and posttest questions (conceptual understanding) and digital literacy questionnaire, Aiken's V analysis was used to assess content validity. Aiken's V is a validity coefficient that measures the level of agreement between raters (in this case, experts) regarding the relevance or suitability of each instrument item to the measurement objectives. The value of Aiken's V coefficient ranges from 0 to 1. The higher the V value approaches 1, the higher the experts' agreement that the item is valid and relevant. In this study, question items that have an Aiken's V value ≥ 0.8 are considered to have strong content validity and are suitable for use in research. This ensures that the instrument used measures the intended construct accurately.

▪ RESULT AND DISSCUSSION

Development of Physics E-Book

During the analysis stage, four main types of analysis were conducted: needs analysis, literature analysis, curriculum analysis, and student characteristics analysis (Branch, 2009). Needs analysis was conducted through interviews, observations, and documentation studies to identify the learning media used thus far. The results showed that physics learning has not effectively used digital media and remains teacher-centered. Next, a literature analysis was conducted to compile previous findings related to the use of Problem-Based Learning (PBL)-based learning media in physics education and the importance of digital literacy. This analysis provided the theoretical basis for media development. A curriculum analysis was then conducted to identify the alignment of core competencies, core content, and learning outcomes on the topic of work and energy in the "Merdeka" Curriculum. The analysis phase concluded with an identification of student characteristics, which revealed that most students perceive physics as a complex and boring subject, leading to a lack of interest in learning physics.

In the design stage, the results of the analysis stage are used as the basis for developing the initial product design. The design process begins with the creation of a media design in the form of an interactive PBL-based e-book, complete with a storyboard that illustrates the content flow, interactive features, and navigation between sections. Each chapter in the e-book is designed following the PBL syntax, namely problem orientation, data collection, data analysis, solution development, and reflection. To ensure the quality of the media, a validation rubric is also developed, covering aspects of content suitability, media display quality, integration with the PBL syntax, and ease of use. This rubric is used by validators to assess the suitability of the product. Additionally, supporting instruments were designed, including teaching modules, pretest-posttest questions, a digital literacy questionnaire, and a student response questionnaire. The e-book prototype was designed using a combination of software, such as Canva for visual design, Heyzine to convert documents into an interactive flipbook-based e-book, and Google Forms for data collection from evaluation instruments.

The development stage began with the creation of an initial prototype based on the design that had been developed. The initial e-book product and its supporting instruments were then validated by experts, in this case, physics teachers, to assess the suitability of the content and appearance. The validation results showed that the e-book received an average score of 3.83 and the teaching module received 3.85, both categorized as "Very Good". The digital literacy questionnaire and pretest-posttest questions were validated using Aiken's V analysis, with values of 0.98 and 0.89, respectively, and categorized as "Very Valid". Meanwhile, the student response questionnaire obtained an average score of 4.00, indicating that the instrument is highly suitable for use. All research instruments were deemed suitable for use in a limited pilot study.

In addition to validation, technical checks were also conducted, and several issues were identified, such as external links in the e-book that could not be accessed, platform compatibility issues (especially on mobile devices), and internet connectivity limitations in some locations. These findings highlight the importance of developing adaptive digital resources, including providing offline access alternatives such as downloadable videos and simulations. Before being used in the implementation phase, the product was first refined based on the validation results. The final e-book development product can be viewed in Figure 1 or by clicking the following link: Link E-Book: https://heyzine.com/flip-book/d3412fc6cb.html

Figure 1. Design e-book

Next, the implementation stage involved testing the validated interactive e-book based on Problem-Based Learning in classrooms using a quantitative approach with a pre-experimental design, specifically a One-Group Pretest–Posttest Design. This design was selected because it was appropriate for early product development studies and did not include a control group or randomization. The e-book was used as the primary medium for learning the topic of Work and Energy, while the teaching module served as a guide for teachers. Students accessed the e-book through their own devices online using the Heyzine platform as a medium for presenting interactive flipbooks. The learning process focused on student engagement in solving contextual problems step by step, following the PBL syntax, and was complemented by evaluation through pretest and posttest to measure concept mastery. Additionally, students also completed a digital literacy questionnaire and a questionnaire on their response to the media used.

The evaluation stage was carried out in two forms, namely formative evaluation and summative evaluation. Formative evaluation was carried out during the implementation process to identify technical and pedagogical obstacles that may arise. One important finding at this stage is the issue of accessibility to several learning resources embedded in e-books, such as links to interactive simulations, learning videos, and additional online articles. Some causes of these challenges include broken links, device compatibility issues, and limited internet access in certain school locations. This issue is an important consideration in the development of digital media because even if the content is well-designed pedagogically, failures in digital infrastructure can hinder the effectiveness of learning. Therefore, it is recommended that developers regularly validate links, provide offline-accessible resources, and prepare alternative options such as downloadable videos or offline HTML-based simulations.

Summative evaluation was conducted through analysis of pretest and posttest data, digital literacy questionnaires, and student responses to the media. The results showed an increase in concept mastery scores after using the e-book, as well as an improvement in students' digital literacy. Student responses to the e-book were also very positive, indicating that the media was considered engaging, easy to understand, and helpful in learning concepts previously deemed difficult. Overall, the ADDIE model is deemed highly suitable for application in the research and development of this media, as it functions optimally to identify needs, develop innovative solutions, and evaluate the initial effectiveness of the product before implementation on a larger scale.

Thus, the ADDIE stages successfully supported the development of PBL-based e-books on the topic of Work and Energy, which are not only content- and design-appropriate but also effective in enhancing conceptual understanding and students' digital literacy in problem-based learning.

Effectiveness of Using Physics E-Book

Then, this study also obtained data to analyze the effectiveness of the e-book developed. One of the data obtained was data on student responses to the e-book was also collected. The data was then analyzed to assess the feasibility and acceptability of the developed e-book. The analysis was conducted using Ideal Standard Deviation (SBi).

The overall assessment, which includes the quality and relevance of its content, resulted in an average score of 3.60 ("Very Good"). This indicates that the e-book's subject matter is well structured and highly relevant. In terms of display, the e-book scored 3.62 ("Very Good"), signifying that its visual design, layout, and interactive element, such as embedded simulations and self-assessment features, significantly enhanced student engagement and their learning experience. Furthermore, the language used within the e-book also received a "Very Good" score of 3.60, signifying that students found it clear, easily comprehensible, and conducive to understanding complex physics concepts without unnecessary jargon. These robust results collectively underscore the e-book's practicality and suitability for effectively supporting students' conceptual understanding and active participation in their learning journey.

In addition to quantitative responses, qualitative data were also collected through open-ended questions and classroom observations to gain deeper insights into student perceptions. Several students positively highlighted the clarity of the content and alignment with real-life problems. One student commented, “The examples provided help me understand how physics applies to daily life, especially the part about energy in roller coasters.”

In terms of visual design, students appreciated the interactive elements and the integration of hyperlinks to simulations. For instance, a student noted, “The simulation links make it easier to experiment and visualize the concepts, especially energy conversion.” Others found the layout and illustrations engaging and helpful in maintaining focus.

Regarding language use, most students found the instructions easy to follow, but a few suggested that “some of the problem statements could be simplified for better clarity.” Additionally, one student suggested adding a glossary for difficult physics terms, while another recommended including short video explanations for some abstract concepts. These comments were valuable for evaluating not only the e-book’s effectiveness but also its practicality and appeal, especially in supporting student-centered learning through the PBL approach.

The concepts assessed in the 10 items of the pretest and posttest in this study encompass various fundamental aspects of the topic of Work and Energy, which are closely aligned with the objectives of physics education and the Problem-Based Learning (PBL) approach. Questions 1-3 focus on foundational knowledge, covering the definition of work (C1), distinguishing work types (C4), and kinetic energy. Items 4-6 extend this to gravitational potential energy (C3), total mechanical energy, and the Work & Energy Theorem. The latter questions delve into higher-order thinking, with items 7-8 assessing graph interpretation and the Law of Conservation of Mechanical Energy, while questions 9-10 (C4) demand analytical skills for real-life energy transformations, efficiency, and calculating velocity from data using conservation principles.

The results of the analysis of students' conceptual understanding improvement showed that initially, participants demonstrated basic understanding, as indicated by an average pre-test score of 30.44. After the intervention or learning period, their conceptual understanding improved significantly, as indicated by a marked increase in the average post-test score to 80.83. This significant jump of more than 50 points from pre-test to post-test strongly indicates the effectiveness of the teaching method, intervention, or learning experience in improving participants' understanding of these concepts. Such a dramatic improvement is generally interpreted as a positive result, indicating that participants have gained a much deeper and more comprehensive understanding of the subject matter. When viewed from each aspect, the improvement in students' conceptual understanding can be seen in Figure 2.

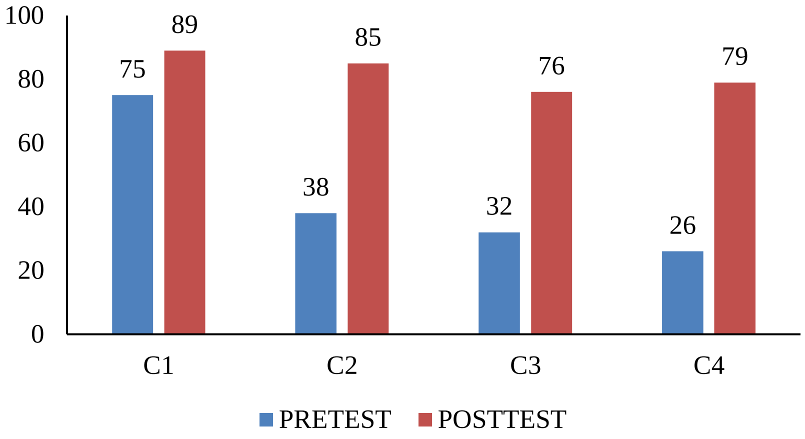

Figure 2. Conceptual understanding improvement

Figure 2 compares the conceptual understanding scores between the pretest and posttest for the four aspects (C1, C2, C3, and C4). Overall, there was a dramatic and consistent improvement across all aspects, with the orange bars always much higher than the blue bars. The sharpest improvement was seen in aspect C2, which more than doubled from 38 to 85. The same was true for aspect C4, where the score went from 26 to 79, showing a huge improvement. Meanwhile, aspects of C1 saw an increase from 75 to 89, and C3 rose from 32 to 76. These results clearly show that the intervention was very effective in improving conceptual understanding in all four aspects.

Overall, the analysis of the increase in students' conceptual understanding showed an N-Gain score of 0.71, which falls into the “high” category, indicating a substantial improvement. This positive change is closely linked to the specific features embedded in the developed PBL-based e-book. The "Problem Orientation" section (Figure 1) served as a crucial starting point for activating students' prior knowledge by presenting real-world scenarios such as a roller coaster's motion or objects falling due to gravity. These contextual problems engaged students, sparked curiosity, and fostered a desire to learn, aligning with the principles of PBL as a constructivist learning model. This is consistent with research showing that the PBL learning model can make students more active and reflective (Argaw et al., 2017).

In addition, the "Work Steps" phase, which integrates PhET interactive simulations, played a significant role in helping students visualize abstract physics concepts, particularly energy transformation between kinetic and potential energy. Students were able to observe these processes dynamically, helping them overcome common misconceptions related to the Work & Energy Theorem and the Conservation of Mechanical Energy. Such visual and interactive learning environments help reduce extraneous cognitive load and enhance conceptual clarity, especially when learners process information through both verbal and visual channels simultaneously.

Comparatively, the results of this study align with and slightly exceed findings from similar research. For instance, (Hawa et al., 2021), who also implemented PBL with PhET simulations in high school physics education, reported an average N-Gain of 0.65. The slightly higher score in this study (0.71) may be attributed to the more structured scaffolding provided through the e-book format, which included consistent prompts, visual guides, and embedded questions aligned with PBL syntax. This is also supported by Hill & Sharma (2015), which shows that digital-based learning with PhET assistance can improve students' conceptual mastery.

In terms of specific conceptual gains, the most significant improvement was observed in the understanding of mechanical energy conservation and energy transformation in real-life scenarios, likely due to the visual clarity offered by simulations. Conversely, the lowest improvement was found in the topic of energy loss due to friction and non-conservative forces, suggesting that students still face challenges when reasoning about dissipative processes in open systems. This points to a need for more targeted scaffolding or perhaps additional simulations focusing on these phenomena.

Besides improving conceptual understanding, this study also investigated students' digital literacy skills through a 20-item questionnaire. The results indicate a rise from an average score of 2.45 to 3.47 post-intervention, yielding an N-Gain of 0.66, also categorized as "high." The interactive e-book encouraged students to access and interpret online simulations, reflect through digital response fields, and navigate embedded resources. Students also reported higher confidence in selecting credible online information and operating learning technology tools skills which are essential for 21st-century learners.

These findings carry practical implications for physics educators. The integration of PBL into interactive e-books has proven to be an effective strategy not only for enhancing conceptual understanding but also for simultaneously developing digital literacy, two crucial competencies in modern science education. Teachers are encouraged to adopt this model by gradually incorporating problem-based digital materials into their lessons. However, potential implementation challenges must be acknowledged, such as unequal access to devices, limited internet connectivity, and teachers' unfamiliarity with PBL facilitation. To address these, schools should invest in ICT infrastructure, provide professional development training, and encourage peer collaboration among educators to build a supportive environment for this innovation.

In summary, the observed improvements in both conceptual understanding and digital literacy underscore the value of integrating PBL into e-books enriched with interactive simulations and real-world contexts. This approach not only aligns with educational theories such as constructivism and multimedia learning but also offers a promising and scalable solution for advancing physics education in the digital age.

The data shows a significant improvement in students' digital literacy after engaging with the PBL-based e-book. This is in line with research by Lahnwong (2019), which states that after being given treatment, several aspects of digital literacy, such as information, collaboration, communication, and creativity, increased. In this study, the results of digital literacy improvement in each aspect can be seen in Figure 3.

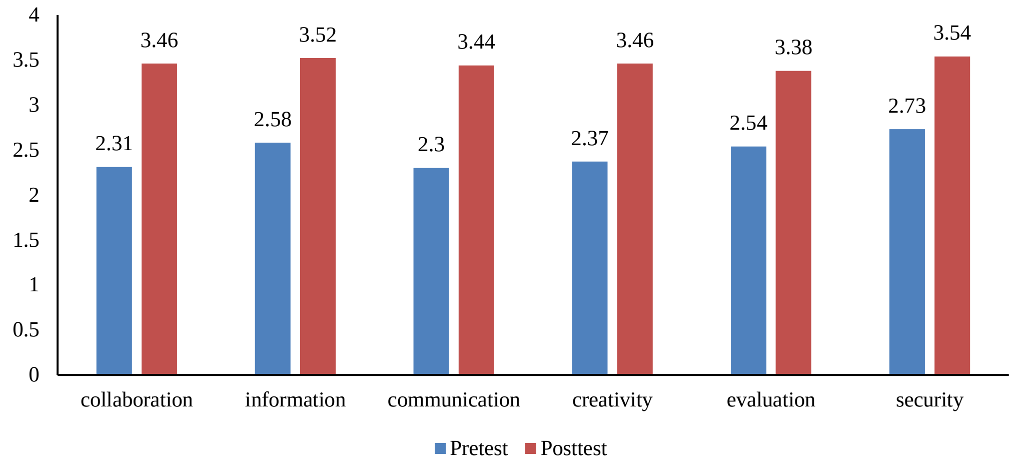

Figure 3. Digital literacy improvement

Figure 3 compares the pretest and posttest digital literacy scores in six aspects: collaboration, information, communication, creativity, evaluation, and security. Consistent improvement is seen across all aspects, where the red bars are always higher than the blue bars. The highest improvement occurred in the “information” aspect, with a pretest score of 2.58 increasing to 3.52 in the posttest. The “security” aspect also showed a significant increase from 2.73 to 3.54. In addition, the other four aspects of collaboration, creativity, communication, and evaluation also showed a good improvement. Thus, overall, this data shows that the intervention successfully improved digital literacy competencies in all aspects measured.

Additionally, this study also conducted a T-test analysis using SPSS Statistics 25 software. The results showed that the significance values for both variables, conceptual understanding and digital literacy were below 0.05. Thus, it can be concluded that there was a significant difference between the pretest and posttest results of the students on both variables.

Beyond the technical reflections, this study's methodological limitations must also be acknowledged. The research utilized a one-group pretest–posttest design, which, while suitable for initial feasibility testing, lacks a comparison group, limiting the strength of inferences about the e-book’s effectiveness. The absence of a control group introduces potential threats to internal validity, such as testing effects and maturation. To build on the promising initial findings of this study, several specific and actionable research designs are recommended for future investigations:

1. Quasi-Experimental Design: Implement a non-equivalent control group pretest-posttest design. For instance, class X5 can serve as the experimental group using the PBL-based e-book. In contrast, a parallel class with similar academic characteristics can serve as a control group receiving conventional instruction (e.g., lecture and textbook). This design will provide stronger causal inference and more robust conclusions regarding the e-book’s impact.

2. Mixed-Methods Study: To capture the “why” and “how” behind student learning experiences, integrate qualitative data through semi-structured interviews with a stratified sample of 6–8 students representing high, medium, and low achievement levels. Interview questions could explore which aspects of the e-book were most helpful or confusing, and how the e-book influenced their approach to learning the physics concepts of work and energy.
3. Longitudinal Study: To assess retention of conceptual understanding, conduct a follow-up test 2–3 months after the posttest. This would determine whether conceptual gains from the PBL-based e-book are long-lasting compared to more traditional methods. Insights from such a study could influence curriculum integration strategies at a broader scale.

▪ CONCLUSION

This study provides promising preliminary evidence that the integration of the Problem-Based Learning (PBL) model into an interactive e-book format is an effective strategy not only for improving students' conceptual understanding in physics but also for simultaneously developing their digital literacy, two essential competencies in 21st-century science education. The development of the e-book using the ADDIE model resulted in a highly valid and well-received learning product, as confirmed through expert validation and positive student responses regarding the content, appearance, and language used.

Empirical findings from limited trials indicated substantial gains in student outcomes, with an N-gain score of 0.71 for conceptual understanding and 0.66 for digital literacy, both categorized as high. These improvements suggest that the structured use of PBL syntax in combination with interactive multimedia features such as problem orientation and PhET simulations can create a meaningful and engaging learning experience for students, particularly on complex topics like work and energy. Additionally, this study conducted a t-test analysis, the results of which showed that the difference between pre-test and post-test scores for both variables was statistically significant, further reinforcing the effectiveness of the developed e-book.

However, it is important to acknowledge that the use of a one-group pretest–posttest design limits the strength of causal claims and generalizability of the findings. The absence of a control group and the limited sample size mean that results should be interpreted with caution. Therefore, future research should employ more rigorous experimental designs, such as quasi-experimental or randomized controlled trials, to validate and expand upon these results in more diverse contexts and larger populations.

Despite its limitations, this study contributes to the growing body of research on digital learning innovation and demonstrates the potential of combining PBL with technology-enhanced learning environments. It also offers practical implications for educators seeking to improve physics learning through student-centered and digitally rich instructional tools.

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