Interactive Physics e–Learning Media to Improve High School Students' Science Literacy on Renewable Energy Material

Nara Abdullah Sufi Al Amin Sabilillah[1]*, Wisnu Catur Hidayat[2]
[1]*Pendidikan Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Negeri Jakarta, Jakarta, Indonesua*
[2]*Fisika, Fakultas Matematika dan Ilmu Pengetehuan Alam, Universitas Negeri Jakarta, Jakarta, Indonesua*

ABSTRACT
21st-century science education demands the mastery of scientific literacy to solve global issues. However, a significant research gap remains existing instructional tools often fail to connect theoretical physics concepts with real-world energy crises, leaving students' critical reasoning unstimulated. This study aims to develop and evaluate the feasibility, practicality, and effectiveness of an interactive PowerPoint (PPT) media based on Problem-Based Learning (PBL) as an e-learning instrument solution. This study employed a Research and Development (R&D) method using the ADDIE (Analyze, Design, Develop, Implement, Evaluate) instructional design. The research subjects involved Grade X students divided into experimental and control groups. Data were collected using expert validation questionnaires, student response questionnaires, and scientific literacy tests (pre-test and post-test). Product evaluation by experts indicated a "Very Feasible" criterion with average validity scores for matter at 90.30%, language at 88.16%, and media at 91.60%. Classroom implementation yielded a practicality rate of 93.90% (Very Practical). Effectiveness testing using N-Gain analysis demonstrated that the experimental group (0.64) outperformed the control group (0.41). The statistical t-test result is 7.6439 that is <0.05 confirmed a significant difference in improvement. It is concluded that the integration of the PBL syntax into the non-linear navigation of an interactive e-learning media is a very feasible, practical, and effective instructional medium to boost the scientific literacy competencies of high school students.

ABSTRAK
Pendidikan sains abad ke-21 menuntut penguasaan literasi sains untuk memecahkan isu global. Namun, terdapat celah penelitian yakni alat instruksional yang ada saat ini seringkali gagal menghubungkan konsep fisika teoritis dengan krisis energi di dunia nyata sehingga penalaran kritis siswa tidak terstimulasi. Penelitian ini bertujuan untuk mengembangkan serta menguji kelayakan, kepraktisan, dan keefektifan media PowerPoint (PPT) interaktif berbasis Problem-Based Learning *(*PBL*) sebagai solusi instrumen e-learning. Penelitian ini menggunakan metode* Research and Development (R&D) *dengan desain instruksional* ADDIE *(*Analyze, Design, Develop, Implement, Evaluate*). Subjek penelitian melibatkan siswa kelas X yang terbagi ke dalam kelompok eksperimen dan kontrol. Pengumpulan data menggunakan instrumen kuesioner validasi ahli, angket respons siswa, dan tes literasi sains (*pre-test *dan* post-test*). Hasil pengujian produk oleh ahli menunjukkan kriteria "Sangat Layak" dengan skor rata-rata kevalidan materi sebesar 90,30%, bahasa 88,16%, dan media 91,60%. Implementasi di kelas menghasilkan tingkat kepraktisan 93,90% (Sangat Praktis). Uji keefektifan menggunakan analisis N-Gain membuktikan bahwa kelompok eksperimen (0,64) unggul atas kelompok kontrol (0,41). Hasil uji statistik t-test = 7,6439 dimana p < 0,05) menegaskan adanya perbedaan peningkatan yang signifikan. Disimpulkan bahwa integrasi sintaks PBL ke dalam navigasi non-linier PPT interaktif merupakan media pembelajaran yang valid, praktis, dan sangat efektif dalam mendongkrak kompetensi literasi sains siswa SMA.*

CONTACT
narsabillah@gmail.com

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INTRODUCTION

Science education in the 21st century has shifted from mere rote memorization to the construction of higher-order thinking skills, with scientific literacy serving as one of its main pillars (Živković, 2016). Students with adequate scientific literacy are expected to be capable of identifying problems, explaining natural phenomena, and making rational decisions based on scientific evidence (Nasution et al., 2025). However, the landscape of science education in Indonesia still faces significant challenges. Based on the 2022 Programme for International Student Assessment (PISA) report, the scientific literacy of Indonesian students remains a

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significant concern, with an average score of only 383 well below the OECD average of 476 (OECD, 2023). This performance gap suggests that physics education in the country is still largely teacher-centered, focusing predominantly on rote mathematical calculations (Okeke & Ramaila., 2021). Consequently, students' capacity for critical reasoning and independent inquiry has not been fully realized (Sarnou & Dallel., 2021).

This pedagogical challenge is further amplified when students encounter contextual physics topics tied to global crises, such as Renewable Energy. This subject matter transcends simple efficiency formulas, it demands a critical understanding of the climate crisis and the transition toward sustainable energy in line with the Sustainable Development Goals (SDGs) (Alatas & Fauziah., 2020). Ideally, students should possess the scientific literacy necessary to analyze environmental shifts, objectively assess alternative energy sources, and propose scientifically sound interventions (Amsari et al., 2022). In practice, however, this vital material is often reduced to abstract memorization. Such limitations frequently stem from a lack of authentic problem-solving stimulants and a shortage of instructional media capable of visualizing macroscopic energy mechanisms, which students often find difficult to conceptualize (Boma et al., 2024).

To address these systemic barriers, instructional strategies must pivot toward investigation-based learning. In this regard, Problem-Based Learning (PBL) is widely recognized as a highly effective pedagogical framework for advancing scientific literacy (Romi & Radia., 2022). The PBL syntax initiates the learning process through ill-structured, real-world challenges, guiding students to organize their own inquiries, collaborate with peers, and ultimately present viable solutions (Khoiriah & Kholiq., 2019). Current research validates that the various stages of PBL are instrumental in honing analytical skills. By engaging with this model, students move beyond passive consumption, learning instead to deconstruct complex problems and construct their own knowledge is the very core of scientific literacy (Ariadila et al., 2023).

The study highlights that PBL positively affects students' learning independence, with significant associations between the key components of PBL (Novalia et al., 2025). To bridge this instructional gap, the use of interactive PowerPoint (PPT) media offers a practical and highly accessible solution for diverse school environments (Arifin et al., 2021), allowing for better visualization and smoother knowledge integration.

Unlike conventional linear presentation slides, interactive PPT utilizes navigation features such as hyperlinks and triggers, empowering students to control their learning flow independently (Muzijah et al., 2020). Furthermore, this digital media allows the stages of PBL to be systematically integrated into the slide design. For instance, the orientation slide can be specifically designed to present problems through video broadcasts, while the investigation slide provides direct links to virtual simulations.

Based on a review of previous literature, the effectiveness of the PBL model and the utilization of interactive PPT media have been widely investigated separately. However, a specific research gap remains there is a distinct lack of studies that functionally integrate these two variables by embedding the PBL syntax directly into the non-linear navigation framework of an interactive digital media. Recognizing this explicit gap and the urgent need in educational settings, this Research and Development (R&D) study was conducted. It specifically aims to design, develop, and evaluate a PBL-integrated interactive e-learning media to accelerate high school students' scientific literacy regarding complex global issues such as Renewable Energy.

METHOD

This study employs a Research and Development (R&D) design to produce, evaluate, and determine the effectiveness of a specific educational product. The development process utilizes the ADDIE instructional design model, which consists of five systematic and iterative phases: Analyze, Design, Develop, Implement, and Evaluate (Sugiyono, 2021). The ADDIE framework was selected because of its comprehensive and adaptive structure, making it very suitable for designing technology-based instructional media that require continuous formative evaluation (Nurbaya et al., 2025). The study was conducted during the even semester of the academic year, involving Grade X high school students as the research subjects.

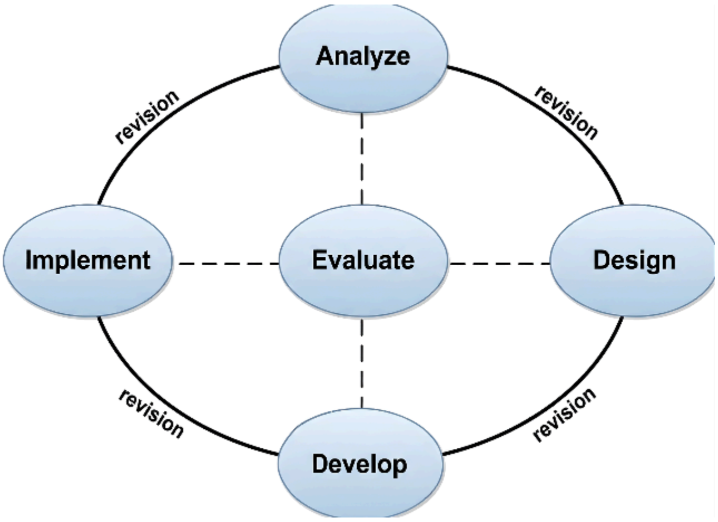

Figure 1. ADDIE Stages

The first phase, Analyze, serves as the foundation of the development process. This phase comprised a needs assessment, curriculum analysis, and student characteristic analysis. Initial data were gathered through direct observations and interviews with physics teachers to identify the gap between the expected scientific literacy competencies and the actual conditions in the classroom, specifically concerning the Renewable Energy topic (Rahayu et al., 2022). Furthermore, an analysis of the students' cognitive development and digital literacy was conducted to ensure that the interactive e-learning Media would be tailored to their learning pace and technological proficiency.

The second phase is Design. In this stage, the researchers formulated specific learning objectives based on the applicable physics curriculum and designed the Prototype of e-learning Media. Concurrently, the researchers designed the data collection instruments, which included expert validation sheets, teacher and student practicality questionnaires, and equipped rubrics based on the four Indicators of scientific literacy defined by Wilkinson (1999), which encompass science as a body of knowledge, a way of investigating, a way of thinking, and the interaction among science, technology, and society.

The scientific literacy test instruments underwent a comprehensive validation process prior to data collection. The content validity was initially established through expert judgment, ensuring strict alignment with the targeted scientific literacy dimensions. Subsequently, the instruments were empirically tested on a non-sample group. The empirical data were analyzed using the Pearson Product-Moment correlation. According to the testing criteria, an item is considered empirically valid if its calculated correlation coefficient is greater than the critical table value at a 5% significance level (Sugiyono, 2021). The analysis yielded item correlation coefficients ranging from 0.506 to 0.752, which successfully exceeded the r-table threshold. Furthermore, the internal consistency reliability was assessed using Cronbach's Alpha. Based on standard psychometric criteria, an instrument is deemed reliable if its Alpha coefficient is strictly greater than 0.70 (Sugiyono, 2021). The assessment resulted in a coefficient of 0.934. These statistical outcomes, having fulfilled all requisite criteria, confirmed that the selected test items were highly valid and possessed a strong degree of reliability for precisely measuring the student's scientific literacy.

Table 1. Indicators of Science Literacy

Dimension	Indicators
Science body of knowledge	Facts of sciences, concepts, principles, and theories related to renewable energy.
Science to investigate knowledge	problems through inquiry and analyzing virtual simulation results.
Science as a way of critical thinking	Deductive/inductive reasoning, empirical evidence, draw logical conclusions.
Science as technology in Society	Impact of renewable energy technologies

(Wilkinson, 1999)

The third phase, Develop, involved the actual production of the interactive e-learning media based on the established storyboard. The presentation was engineered utilizing advanced navigation features (hyperlinks and triggers) and integrated with multimedia elements such as documentary videos on the climate crisis and links to virtual renewable energy simulations (Sutanto et al., 2022). Following the initial production, the prototype was subjected to a rigorous validation process by three physics education experts. The validation data, collected via Likert-scale questionnaires, were quantitatively analyzed using descriptive statistics to determine the percentage of validity.

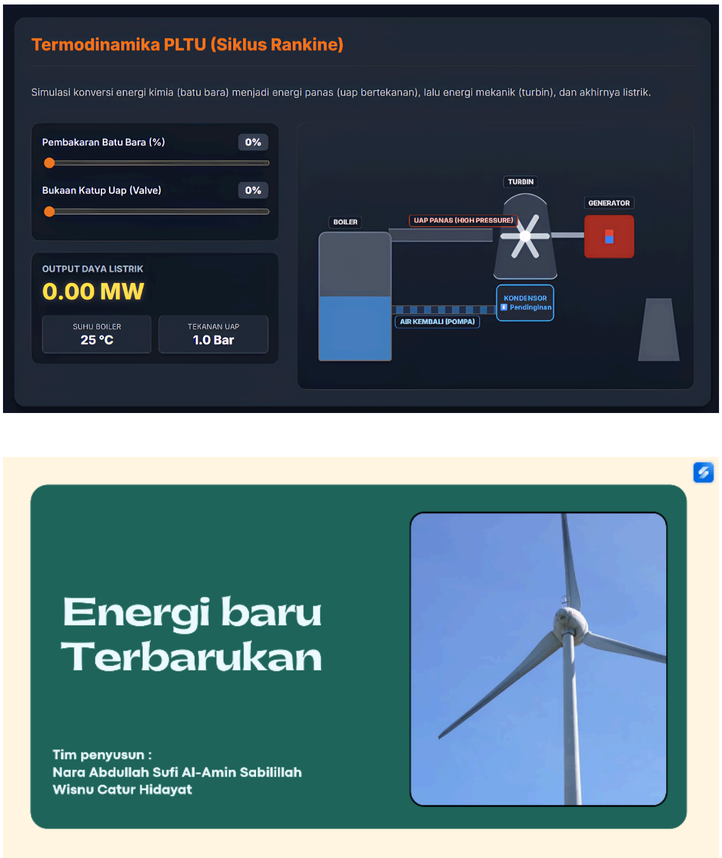

Figure 2. Prototype E- Learning Media

The fourth phase, Implement, was the empirical testing of the validated media in a real classroom setting. This phase adopted a quasi-experimental approach using a Non Equivalent control (Rubini et al., 2019). The revised interactive PPT was implemented during physics lessons on Renewable Energy with a sample of 36 Grade X students in control variable class and 31 students in experimental class . During this phase, practicality data were collected through response questionnaires distributed to the students after the learning process concluded. The practicality score was calculated using a percentage formula to determine the media's ease of use and appeal in an actual educational environment. The resulting percentage was then interpreted using a standardized criteria scale: 0–20% (Very Infeasible), 21–40% (Infeasible), 41–60% (Neutral), 61–80% (Feasible), and 81–100% (Very Feasible) (Sugiyono, 2021).

At this stage, the PBL syntax implementation is executed in full. First, the teacher distributes the interactive PPT slides to the students and presents the problems that they need to solve. The teacher then allocates time for the students to investigate and work independently or in groups. During this group work process, students are encouraged to use their knowledge, initial skills, and information from the PPT to construct their answers. In the following meeting session, students are asked to present the solutions they have formulated using the presentation PPT slides they created themselves. After the presentation, the teacher facilitates a class discussion session and provides time for students to give critical feedback to each other's presented solutions. The implementation stage is the trial phase of using the validated interactive PPT media in the actual classroom learning process.

The final phase, Evaluate, focused on measuring the effectiveness of the developed media in enhancing students' scientific literacy. The primary data sources were the students' scores from the scientific literacy pre-test and post-test. To ascertain the magnitude of improvement, the data were analyzed using the normalized gain score (N-Gain) formula, followed by categorization based on Hake's criteria (Istiyono et al., 2018). Furthermore, inferential statistical analyses including normality tests and paired sample t-tests were conducted using statistical software to determine the significance of the difference between the pre-test and post-test scores. The media is deemed effective if there is a statistically significant improvement in the students' scientific literacy after utilizing the PBL-based interactive PPT

RESULT AND DISCUSSION

This research produces an e-learning instructional medium integrated with scientific literacy on the topic of New and Renewable Energy, specifically implemented for grade X students at SMAN 11 Jakarta. The data collected in this study encompasses the specific characteristics of the teaching materials, expert feasibility validation results, and the profile of students' scientific literacy skill attainment. The content within this digital platform comprehensively addresses coal energy, wind energy, solar energy, and biodiesel utilization, all of which are augmented with interactive simulations to reinforce conceptual understanding. Furthermore, the systematic distribution of each scientific literacy domain adapted in the development of these materials is presented in Table 2.

Table 2. Composition of Science Literacy Aspects in E-learning

Aspects Science Literation	Forms and Sources of Energy	Renewable Energy Transformation	Environmental Impact and Sustainability	Average
Science body of knowledge	42.50%	36.20%	31.50%	36.73%
Science to investigate knowledge	18.20%	26.50%	15.30%	20.00%
Science as a way of critical thinking	19.30%	20.40%	24.80%	21.50%
Science as technology in Society	20.50%	16.90%	28.40%	21.77%

Based on the analysis of the interactive PPT media developed for the Renewable Energy topic, the distribution of scientific literacy content is categorized into four distinct dimensions. The largest portion is dedicated to science as a body of knowledge at 36.73%, followed by science as technology in society at 21.77%, science as a way of critical thinking at 21.50%, and science to investigate knowledge at 20.00%. This specific compositional balance reflects a comprehensive approach to science education, ensuring that students do not just memorize facts but also understand the investigative processes and societal implications of energy technology. Furthermore, this proportion aligns closely with the foundational longitudinal study conducted by Wilkinson (1999), which analyzed the evolution of physics textbooks in Victoria, Australia, over a thirty-year period (1967–1997). Wilkinson observed that an ideal, balanced science literacy content should consist of approximately 42% for the body of knowledge, 18% for the way of investigating, 19% for the way of thinking, and 20% for the interaction among science, technology, and society, which is generally simplified to a 2:1:1 ratio (Husna et al., 2022).

In the Develop phase, the actual production of the interactive e-learning media is involved based on the established blueprint. The media was engineered utilizing advanced navigation features (hyperlinks and triggers) designed with a non-linear flow. The PBL flow is structured around a Main menu that branches into four primary sections: (1) Problem Orientation, featuring on study case of climate changes; (2) Core Concept delivery for Renewable Energy; (3) Scientific Investigation, providing direct hyperlinks to virtual simulations; and (4) Evaluation quizzes. To facilitate easy access for students and educators, a direct digital link to the interactive e-learning media was generated. Following the initial production, the prototype was subjected to a rigorous validation process by three physics education experts to assess its matter, language, and media feasibility.

Table 3. Navigation Flow and Slide Description of the Interactive Media

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<td>


Opening Slide
</td>
<td>In this slide, the educator introduces the topic, outlines the learning objectives, and officially initiates the class session to capture the students attention</td>
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The Study Case Opening
</td>
<td>This slide presents an authentic case study regarding climate change. It is specifically designed to stimulate preliminary critical discussions between the students and the educator</td>
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Core Material
</td>
<td>This section delivers the foundational concepts of general and renewable energy, including a specific case study on Steam Power Plants (PLTU). It further branches into three primary subtopics: Wind Energy, Solar Energy, and Biodiesel</td>
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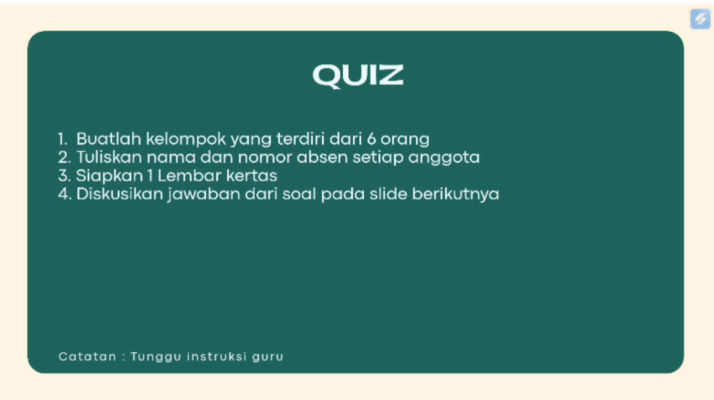

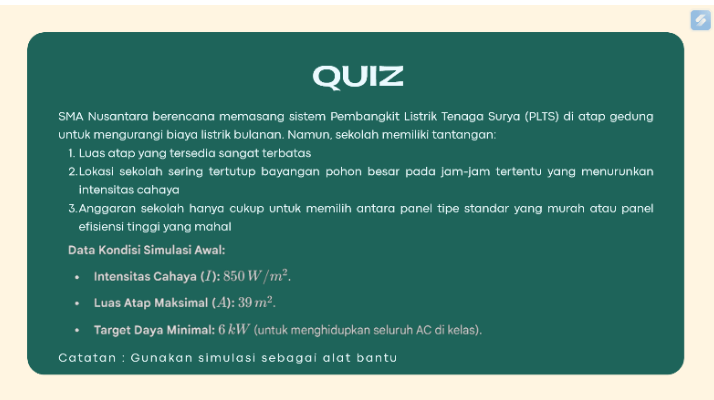

Interactive Quiz Setup
</td>
<td>This slide provides clear instructions for students to form collaborative groups. It sets up the framework for the structured quiz questions they need to solve collectively</td>
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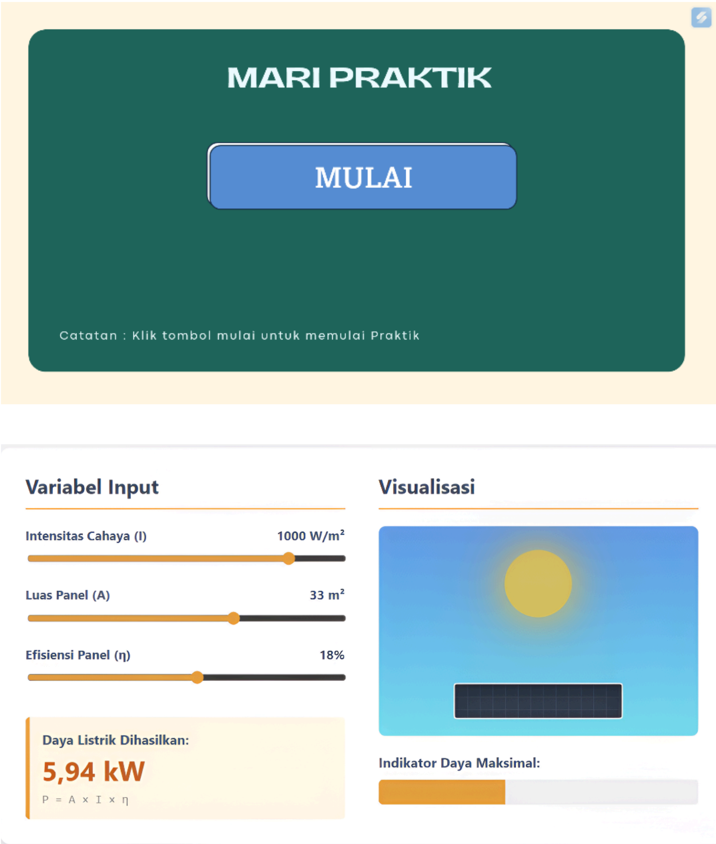
<td>

Interactive Simulation</td>
<td>This slide provides direct hyperlinks to virtual laboratories. Students utilize these interactive simulations to empirically investigate variables and formulate answers for the quiz</td>
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Drawing upon this theoretical framework, the three subtopics integrated into the interactive PPT exhibit an almost perfectly balanced ratio of science literacy content (Sarnou & Dallel., 2021). Therefore, it can be concluded that the developed instructional media provides a very proportionate composition to comprehensively train students' scientific literacy. To determine the quality and eligibility of the developed media, a feasibility test was conducted using expert validation questionnaires. The assessment indicators were adapted from the criteria established by the National Education Standards Agency (BSNP, 2007), which encompass matter feasibility, language suitability, and media interface, (Aini et al., 2023). The validation questionnaires were given to 3 Experts. The result of feasibility testing can be seen in Table 4.

Table 4. Feasibility Test Result

NO	Code	Matter	Language	Media
1	V1	91.20 %	87.40%	90.50%
2	V2	95.30%	91.50%	94.60%
3	V3	84.40%	85.60%	90.50%
Average		**90.30%**	**88.16%**	**91.60%**
Criteria		**Very Feasible**	**Very Feasible**	**Very Feasible**

Following the expert validation, a practicality test was administered involving the 36 Grade X students from the experimental class to evaluate the user experience of the digital media. The results demonstrated that the PBL-based interactive e-learning media achieved a "Very Feasible" criterion (91.60%). This exceptional practicality score indicates that the navigation features, multimedia elements, and instructional sentences embedded within the media were very intuitive and easy to understand, effectively facilitating students in operating the media independently during the learning process.

Figure 3. Implementation

Despite the readability test indicating that the teaching materials generally fall into the "easy-to-understand" category, only 28 students fully met the readability requirements. The observed variations in individual student performance are driven by a complex interplay of determinants, a concept that mirrors the framework established by Keller (1983) and further elaborated by Ibda et al (2023). This theoretical lens suggests that learning outcomes emerge from the intersection of personal and environmental inputs. Specifically, personal inputs encompass: (1) intrinsic motivation or values, (2) the expectancy of success, (3) innate intelligence alongside prior academic mastery, and (4) cognitive evaluation processes. In contrast, environmental inputs focus on external structures, including: (1) motivational management, (2) the strategic organization of learning activities, and (3) the systematic application of reinforcement (Abidin et al., 2017). To measure the efficacy of the developed science literacy-based instructional materials, a post-test was administered. This evaluative step was crucial in determining if the experimental group exhibited a significant advancement in scientific literacy compared to the control group. The assessment utilized the normalized gain score (N-gain), a metric calculated from the pre-test and post-test data of both cohorts to quantify the magnitude of improvement. A detailed summary of these findings, highlighting the trajectory of student skill enhancement, is presented in Table 5.

Table 5. Results of effectiveness

Result	Experiment Group	Control Group
Gain Test	0.64	0.41
t - Test		7.6439

Data presented in Table 3 indicates a clear divergence in the progression of scientific literacy skills between the two study cohorts. The experimental group, which utilized the PBL-based interactive e-learning media, attained an N-Gain score of 0.64. In contrast, the control group achieved a notably lower N-Gain score of 0.41. To validate the statistical weight of this observation, a t-test analysis was conducted. The calculation produced a t-value of 7.6439, which serves as robust inferential evidence to reject the null hypothesis. This result confirms a statistically significant disparity in learning outcomes between the two groups. Therefore, it can be concluded that the implementation of the PBL-integrated interactive media is substantially more effective in elevating students' scientific literacy than traditional instructional approaches.

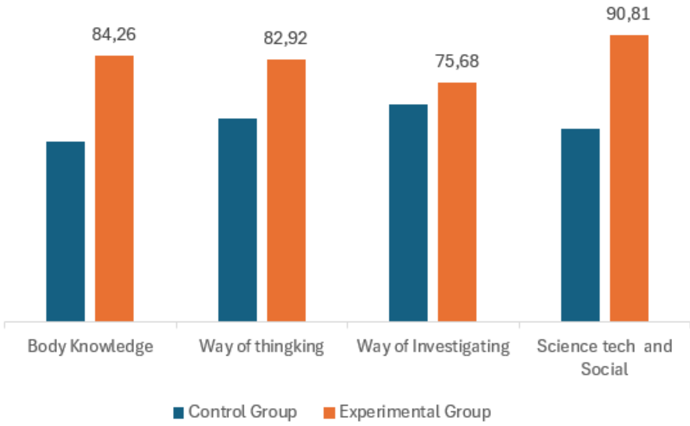

Figure 4. The result Ability of each aspect

The significant improvement in the experimental group's scientific literacy is theoretically grounded in the Constructivist learning paradigm and Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2014). The integration of PBL syntax within interactive e-learning media provided essential cognitive scaffolding. By actively manipulating variables within the virtual simulations to solve authentic climate cases, students transitioned from passive recipients to active knowledge constructors (Hmelo-Silver, 2004). This interactive investigation effectively reduced extraneous cognitive overload, allowing students to seamlessly bridge abstract physics concepts with tangible environmental issues. This theoretical alignment directly explains why the technology and society dimension achieved the highest score (90.81%) in the experimental cohort. This aligns with findings by Dhanil & Mufit (2023), who argue that pedagogical models integrating science, technology, and community contexts significantly refine daily problem-solving skills. Furthermore, the National Science Teaching Association (NSTA) emphasizes that the intersection of science, technology, and society is a fundamental pillar of modern education, essential for making evidence-based decisions regarding contemporary global challenges (Sáenz et al., 2020). In contrast, the control group's post-test results highlighted "science as a process of investigation" as their primary strength. This suggests that using scientific content as a tool for inquiry within specific cases aligns with standard PISA benchmarks (Irwan, 2020). However, these results also echo the study by Budiyanto et al (2019), which found that conventional physics textbooks remain disproportionately focused on theoretical acquisition. Such traditional materials often lack sufficient opportunities for students to engage in critical thinking, hands-on investigative procedures, or explorations of the societal impacts of technology.

The comparative deficit in "science as a way of thinking" among control group students is largely linked to the nature of conventional instructional materials. These textbooks often prioritize algorithmic exercises where students simply insert variables into predefined formulas. This mechanical approach fails to prepare students for the analytical rigor required in conceptual assessments. As Herayanti et al (2017) notes, the capacity to construct complex scientific concepts is not an innate skill but one that requires deliberate, consistent habituation. This is supported by Branch (2009), who asserts that cognitive processing depth is directly proportional to a student's exposure and engagement with a topic. Ultimately, the experimental group demonstrated superior performance across all dimensions of knowledge, investigation, thinking, and societal interaction. This success is attributed to the integration of digital platforms, such as Moodle-based e-learning, which fosters student autonomy and proactive learning. Evidence suggests that these e-learning environments are not only more efficient and user-friendly for physics instruction but also catalyze more significant gains in scientific literacy compared to traditional, passive pedagogical methods.

CONCLUSION

Based on the research findings and discussion, it can be concluded that the development of scientific literacy-based e-learning materials integrated with the Problem-Based Learning (PBL) model for New and Renewable Energy has been effectively implemented for grade X students at SMAN 11 Jakarta. Developed through the ADDIE framework, this medium was declared very feasible by experts across material, linguistic, and media aspects, significantly enhancing students' scientific literacy skills compared to conventional methods. This success was driven by the integration of PBL syntax within the digital platform, which requires students to solve contextual problems through interactive simulations, resulting in the "technology and society" domain achieving the highest achievement percentage. Overall, the synergy between the PBL approach and e-learning tools not only strengthens technical conceptual mastery but also efficiently builds student autonomy and critical thinking skills in analyzing energy solutions for real-world future challenges.

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