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Problem-Based Learning Assisted by Physics Digital Pocket Book: Experimental Study to Enhance Students' Critical Thinking Skills Completed with Bibliometric Analysis toward Sustainable Development Goals (SDGs)

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ABSTRACT

This study presents a bibliometric and experimental investigation of Problem-Based Learning assisted by a Physics Digital Pocket Book (PhyPo) to enhance students' critical thinking skills. Bibliometric analysis indicates increasing research interest in digital learning and problem-based approaches, while highlighting the limited integration of both in physics education. This study employed a true experimental design with a randomized pretest–posttest control group involving high school students. The results show that the implementation of PBL assisted by PhyPo was highly effective, leading to improved critical thinking skills and positive student responses. The integration of interactive digital media and inquiry-based learning enhances engagement and learning outcomes. These findings contribute to the advancement of innovative physics education aligned with sustainable development goals.

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1. INTRODUCTION

The development of education in the 21st century serves as a benchmark for fostering students' 4C skills, namely critical thinking, problem-solving, communication, collaboration, and creativity and innovation. Among these competencies, critical thinking is considered essential, as it is widely discussed in education and plays a significant role in logical reasoning, discussion, and problem-solving. Critical thinking is defined as an intellectual process involving the ability to conceptualize, apply, synthesize, and evaluate information obtained from experience, observation, reflection, or communication as a basis for decision-making and action [1, 2].

Preliminary studies indicate that students' critical thinking skills remain relatively low [3]. Among the indicators, the analysis shows the lowest average, as students often struggle to follow proper procedures in applying formulas to solve problems. One subject that strongly requires critical thinking skills is physics. As a fundamental science, physics examines natural phenomena through scientific processes grounded in scientific attitudes [4-6]. However, physics is still widely perceived as a difficult subject due to its strong association with formulas. Students tend to view it as mere mathematical calculation, and the learning process often emphasizes memorization rather than conceptual understanding [3].

The selection of an appropriate learning model plays a crucial role in the effectiveness of the learning process. Less constructive models tend to limit student engagement and active participation. Problem-Based Learning (PBL) is an instructional model that presents real-world problems as a starting point for analysis and solution development [7]. The PBL model is grounded in several learning theories, including Piaget's cognitive development theory, Ausubel's meaningful learning theory, Vygotsky's social constructivism, Bruner's discovery learning, and John Dewey's experiential learning, all of which emphasize problem-solving and meaningful learning experiences. These theoretical foundations support students' active involvement in constructing knowledge through inquiry, collaboration, and group discussions.

In the digital era, technological advancements and internet accessibility provide significant opportunities to enhance students' learning autonomy [8-10]. Therefore, physics learning should be supported by engaging instructional media and appropriate learning models to create an enjoyable learning experience and reduce students' boredom. One such medium is the digital pocketbook, which is a compact version of a module that is practical to access through technology [11]. Digital pocketbooks present summarized and easily understandable materials, making them suitable for supporting learning activities.

Previous studies have demonstrated that the Problem-Based Learning (PBL) model is effective in improving students' critical thinking skills. Research by some papers [12] reported a moderate increase in critical thinking skills, as indicated by N-gain and significant differences between pretest and posttest scores. Similar findings were reported by some papers [13], showing improvements in analysis and synthesis indicators across high and medium categories. Furthermore, other studies [14-20] consistently indicate that PBL significantly enhances critical thinking skills in physics and science learning.

On the other hand, the use of digital learning media has also been proven effective in supporting physics learning. Android-based pocketbooks have demonstrated effectiveness based on established criteria [21]. In addition, pocketbooks are effective in fostering critical thinking skills, and digital pocketbooks are feasible based on high validation results [22, 23].

Furthermore, studies [24, 25] indicate that mobile learning-based media are effective in enhancing physics learning outcomes. Although previous studies have confirmed the effectiveness of PBL and digital media separately, research integrating the PBL model with Android-based digital pocketbooks, particularly on global warming materials, remains limited. Therefore, this study aims to examine the implementation of the Problem-Based Learning model supported by digital pocketbooks and to analyze its impact on students' critical thinking skills in learning global warming concepts.

Based on the above description, it is necessary to implement innovative learning models to improve students' critical thinking skills, particularly for Grade X students in the independent curriculum. This study focuses on examining the implementation of the Problem-Based Learning (PBL) model supported by a digital pocketbook, PhyPo, as a learning medium to enhance students' critical thinking skills. Accordingly, this study is guided by the following research questions:

(i) What are the results of the implementation of the PBL model assisted by PhyPo in improving students' critical thinking skills?

(ii) To what extent can students' critical thinking skills be improved after the implementation of the PBL model assisted by PhyPo?

(iii) How do students respond to the implementation of the PBL model assisted by PhyPo?

In addition, recent bibliometric trends reveal a significant increase in studies focusing on digital learning media and problem-based learning approaches in science education. However, limited research has integrated both strategies within a single instructional framework, particularly in physics learning contexts. This study addresses this gap by combining Problem-Based Learning with a Physics Digital Pocket Book (PhyPo) to enhance students' critical thinking skills. The novelty of this research lies in the integration of interactive digital media with inquiry-based pedagogy in a structured learning model. Furthermore, this study contributes to sustainable development goals (SDGs) by promoting quality education (SDG 4), fostering critical thinking and lifelong learning skills, and supporting digital transformation in education.

2. LITERATURE REVIEW

A digital pocketbook is a compact version of a module designed to provide practical and accessible learning materials. Its small size allows it to be easily stored and accessed through digital devices [26]. Digital pocketbooks present summarized content that is easier for students to understand [27]. Previous studies [28] have shown that digital pocketbooks can enhance students' interest and learning outcomes while creating a more engaging learning experience. In addition, their use contributes to more meaningful and less monotonous learning [29].

In this study, the digital pocketbook application is called PhyPo (Physics Pocket), which serves as an accessible learning medium that can be used anytime and anywhere. PhyPo is designed to support students' critical thinking skills by integrating student worksheets within a lightweight application. The design of the PhyPo application is presented in **Figure 1**.

PhyPo consists of several main features, including the homepage, a digital pocketbook containing learning materials, teacher modules, student worksheet I, student worksheet II, and developer information. The pocketbook menu presents concise materials that are aligned with the intended learning outcomes, making them easier for students to comprehend.

Meanwhile, student worksheet I and student worksheet II are designed to facilitate problem-solving activities in accordance with the PBL syntax. Additionally, the teacher module serves as a guideline to support the effective implementation of the learning process.

Figure 1. PhyPo homepage.

3. METHODS

This study employed a true experimental design using a randomized pretest–posttest control group design. The population consisted of four classes of Grade X students at SMAN 16 Surabaya (N = 140). Based on a 5% error tolerance, a sample of 104 students was selected and randomly assigned into three groups: Experimental Class 1, Experimental Class 2, and Control Class. Experimental Class 1 received instruction using the Problem-Based Learning (PBL) model assisted by a digital pocketbook (PhyPo). Experimental Class 2 was taught using the PBL model supported by PowerPoint media, while the Control Class was instructed using conventional teaching methods, including lectures and exercises. The study was conducted at a senior high school in Surabaya from October 2022 to April 2023. Each learning session lasted 2 × 45 minutes, and all classes were taught by the same teacher to ensure consistency in instruction.

3.1. Instrument

This study utilized several research instruments to collect data. The learning implementation observation sheet was used to evaluate the extent to which classroom activities were conducted in accordance with the PBL syntax. Observations were carried out during the instructional process to ensure the fidelity of the model implementation.

To assess students' critical thinking skills, an eight-item essay test was administered as both a pretest and a posttest. The test items were developed based on critical thinking indicators to measure students' abilities before and after the intervention. Additionally, a student response questionnaire based on a Likert scale was distributed following the implementation of PBL assisted by PhyPo to examine students' perceptions of the learning process.

Before implementation, all learning materials and research instruments were validated by experts to ensure their appropriateness. The validation results indicated that the instruments ranged from valid to very valid. Furthermore, reliability analysis using Cronbach's Alpha yielded coefficients ranging from moderate to high, indicating that the instruments were sufficiently reliable for data collection [30-32].

3.2. Instrument validity and reliability

The validation results indicated that all learning devices and research instruments met the required validity criteria. The average validation scores ranged from 3.00 to 4.00 on a four-point scale. The lesson modules for both experimental classes achieved a mean score of 3.63 (very valid), while the digital media modules obtained a mean score of 3.58 (very valid). The student worksheets scored 3.72 (very valid), and the pretest–posttest instruments were categorized as valid with a mean score of 3.00. In addition, the teacher observation sheet (3.90), student observation sheet (4.00), and student response questionnaire (3.80) were all classified as very valid [30].

Reliability analysis using Cronbach's Alpha showed coefficients ranging from 0.68 to 0.90. The lesson modules demonstrated a reliability coefficient of 0.72 (high), while the digital media ranged from 0.77 to 0.86 (high). The student worksheets achieved a coefficient of 0.90 (high), and the pretest–posttest instrument reached 0.80 (high). Meanwhile, the teacher observation sheet showed a coefficient of 0.68 (moderate), whereas the student observation sheet (0.71) and student response questionnaire (0.78) were categorized as highly reliable. These findings indicate that the instruments were sufficiently reliable for data collection [33].

3.3. Data analysis

Data were analyzed using both descriptive and inferential statistics. Before hypothesis testing, prerequisite analyses were conducted, including tests of normality using the Kolmogorov–Smirnov and Shapiro–Wilk tests, as well as homogeneity of variances using Levene's test [34]. If the data met the assumptions for parametric testing, a paired sample t-test was employed to examine differences between pretest and posttest scores. Otherwise, the non-parametric Wilcoxon Signed Rank Test was applied. The results of the normality tests for both pretest and posttest data are presented in **Table 1**.

Table 1. Normality test results of pretest and posttest scores.

GROUP	KOLMOGOROV–SMIRNOV STATISTIC	DF	SIG.	SHAPIRO–WILK STATISTIC	DF	SIG.
Pretest Experimental 1	0.12	35	0.20	0.93	35	0.04
Posttest Experimental 1	0.32		0.00	0.79		0.00
Pretest Experimental 2	0.14		0.06	0.96		0.22
Posttest Experimental 2	0.17		0.00	0.89		0.00
Pretest Control	0.14		0.05	0.95		0.13
Posttest Control	0.12		0.15	0.97		0.47

Several significance values were found to be below 0.05, particularly in the posttest scores of the experimental groups, indicating that the data were not normally distributed. Therefore, non-parametric statistical analysis was applied in subsequent testing. Homogeneity of variance was assessed using Levene's Test, which showed that the significance values for both pretest (Sig. = 0.42) and posttest (Sig. = 0.42) were greater than 0.05. This indicates that the data were homogeneous and that the variances among groups were equal.

The improvement in students' critical thinking skills was measured using the normalized gain (N-gain) score and categorized into low, medium, or high levels. In addition, effect size (Cohen's d) was calculated to determine the magnitude of the treatment effect [30]. Student responses were analyzed using percentage calculations based on a four-point Likert scale (strongly agree, agree, disagree, strongly disagree). The total score for each item was divided by the maximum possible score and converted into percentages to determine the overall response category.

4. RESULTS AND DISCUSSION

4.1. Implementation of PBL assisted by PhyPo

4.1.1. Teacher Activity

The implementation of the PBL model assisted by PhyPo was observed by three observers. The results indicated that the overall mean score for teacher activity was 3.86, with a percentage of 96.43%, which falls into the very good category. This finding suggests that the learning process was conducted effectively in accordance with the PBL framework. Nearly all phases of the PBL syntax, including problem orientation, organizing students, guiding investigation, developing and presenting work, and evaluation, were implemented properly. As shown in **Table 2**, the high level of implementation fidelity (M = 3.86; 96.43%) indicates that all phases of the PBL model assisted by PhyPo were carried out consistently and in alignment with the planned instructional design.

Table 2. Implementation fidelity of PBL assisted by PhyPo.

PHASE	MEAN	PERCENTAGE (%)	CATEGORY
Opening	4.00	100.00	Very Good
Problem Orientation	4.00	100.00	
Organizing Students	3.83	95.83	
Guiding Investigation	3.83	95.83	
Developing & Presenting Work	3.67	91.67	
Evaluation	3.89	97.22	
Closing	3.83	95.83	
Overall Mean	**3.86**	**96.43**	

The highest scores were obtained in the opening phase, problem orientation, and evaluation stages (100.00%), while slightly lower scores were observed in the presentation phase (83.33%). These findings indicate that the instructional process was implemented consistently in accordance with the PBL framework.

Teacher activities were observed and evaluated to determine their alignment with the PBL stages outlined in the lesson plan. The observations were conducted by three observers, consisting of one physics teacher and two undergraduate students majoring in Physics Education. A total of 14 aspects of teacher activity were assessed based on their conformity with the PBL syntax, including the opening phase, problem orientation, organizing students, guiding investigation, developing and presenting work, analyzing and evaluating the problem-solving process, and the closing phase.

Overall, teacher activity achieved a mean score of 3.86 with an implementation percentage of 96.43%, categorized as very good. This result indicates that the learning process conducted during the 2 × 45-minute sessions was highly consistent with the PBL framework, with nearly all stages of the lesson plan implemented effectively.

4.1.2. Students' activity

Student activities were observed throughout the learning process to assess their alignment with critical thinking indicators. Across all classes, the highest performance was consistently found in the interpretation indicator. In Experimental Class 1, interpretation was followed by evaluation and inference, while analysis obtained the lowest score. Similarly, in Experimental Class 2 and the control class, interpretation remained the highest-performing indicator, whereas inference showed the lowest performance (see **Figure 2**).

Figure 2. Comparison of student activity across research classes.

As shown in **Figure 2**, Experimental Class 1 achieved the highest overall mean score (M = 3.60; 90.00%), categorized as very good, followed by Experimental Class 2 (M = 3.20; 80.00%) and the control class (M = 2.75; 68.75%). These results indicate that the implementation of PBL assisted by PhyPo led to higher student engagement compared to other instructional approaches.

Student activities were further analyzed based on critical thinking skill indicators within the PBL framework. Observations were conducted during each 2 × 45-minute session. In Experimental Class 1, the highest score was observed in the interpretation indicator (3.66), while the lowest was in the analysis indicator (3.54). At the early stages of learning, students experienced difficulties in analyzing contextual physics problems, particularly those related to real-life applications, which is consistent with previous findings.

In Experimental Class 2, interpretation also recorded the highest score (3.31), whereas inference showed the lowest performance (3.03). Similarly, in the control class, interpretation remained the highest (2.86), while inference was the lowest (2.63). Students in these groups faced challenges in concluding, especially when required to independently identify and present real-life physics problems.

Overall, Experimental Class 1 demonstrated the highest level of student activity, categorized as very good, while Experimental Class 2 and the control class were categorized as good. These findings suggest that the implementation of the PBL model assisted by PhyPo was more effective in promoting student engagement and supporting the development of critical thinking skills.

4.1.3. Improvement of critical thinking skills

The Kolmogorov–Smirnov normality test indicated that several pretest and posttest data sets had significance values below 0.05, suggesting that the data were not normally distributed. In contrast, the homogeneity test using Levene's Test showed p-values greater than 0.05 for both the pretest and posttest (Sig. = 0.42), indicating that the variances across groups were homogeneous. Since the assumption of normality was not met, a non-parametric Wilcoxon Signed Rank Test was employed. The results of the test revealed that all experimental and control groups showed significant differences between pretest and posttest scores ($p < 0.05$) (see **Table 3**), indicating that the learning interventions led to significant improvements in students' performance.

Table 3. Wilcoxon signed-rank test results.

CLASS	Z	P-VALUE	INTERPRETATION
Experimental 1 Experimental 2 Control	-5.19	< 0.001	Significant

Positive ranks were observed across all groups, indicating that posttest scores were higher than pretest scores. These findings demonstrate that the learning interventions implemented in all classes contributed to improvements in students' critical thinking skills.

Improvements were evident across all critical thinking indicators. As shown in **Figure 3**, the highest posttest score was achieved in the interpretation indicator (4.76), followed by analysis (4.33), inference (3.39), and evaluation (3.09). Although all indicators showed improvement compared to the pretest, evaluation remained the lowest-performing indicator. These results suggest that the learning intervention was particularly effective in enhancing students' abilities in interpreting and analyzing problems. However, the relatively lower improvement in evaluation skills indicates that higher-order thinking processes, such as judgment and reflection, may require more time or more intensive instructional support.

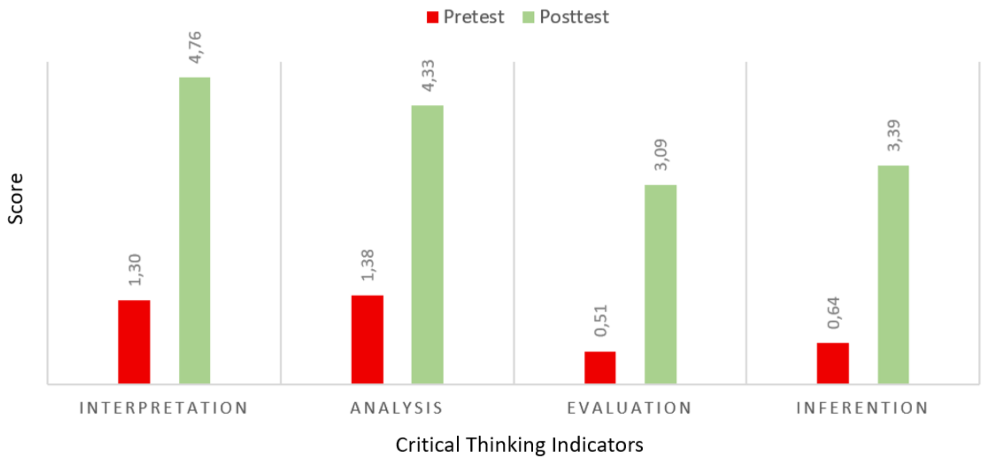


Figure 3. Pretest and posttest scores based on critical thinking indicators.

The N-gain analysis presented in **Table 4** revealed varying levels of improvement across the groups. Experimental Class 1 achieved a medium gain (g = 0.66), while Experimental Class 2 (g = 0.17) and the Control Class (g = 0.13) were categorized as low. These results indicate that the implementation of PBL assisted by PhyPo led to a substantially greater improvement in students' critical thinking skills compared to the other instructional approaches. This finding suggests that integrating PBL with digital pocketbook media provides a more effective learning experience in enhancing students' critical thinking abilities.

Table 4. N-Gain scores of critical thinking skills.

CLASS	N-GAIN	CATEGORY
Experimental 1	0.66	Medium
Experimental 2	0.17	Low
Control	0.13	Low

Moreover, the effect size analysis presented in **Table 5** further supports these findings. Experimental Class 1 demonstrated a medium effect size (d = 0.77), followed by Experimental Class 2 (d = 0.53), while the Control Class showed a very low effect size (d = 0.11). These results indicate that the integration of the PBL model with PhyPo had a stronger practical impact on improving students' critical thinking skills compared to both the PBL model without PhyPo and conventional instruction.

Table 5. Effect size of learning intervention.

CLASS	COHEN'S D	CATEGORY
Experimental 1	0.77	Medium
Experimental 2	0.53	Medium
Control	0.11	Very Low

The improvement in students' critical thinking skills was reflected in the comparison between pretest and posttest scores. The test instruments consisted of essay questions designed to assess key critical thinking indicators, including interpretation, analysis, evaluation, and inference. The pretest was administered to measure students' initial critical thinking abilities, while the posttest was used to evaluate their skills after the implementation of the PBL model assisted by digital pocketbooks.

The level of improvement was measured using the N-gain score, preceded by prerequisite tests, namely normality and homogeneity tests. The normality test showed p-values < 0.05, indicating that the data were not normally distributed and that H0 was rejected. This result is consistent with findings that large sample sizes may lead to deviations from normal distribution [35]. The homogeneity test was conducted using Levene's test to assess the equality of variances across multiple groups [36]. The results showed significance values greater than 0.05, indicating that the data were homogeneous and that H0 was accepted. Conducting homogeneity tests is essential to ensure the validity and reliability of research findings [37].

To determine the improvement in students' critical thinking skills after the prerequisite tests, a difference test was conducted. In this study, the Wilcoxon Signed Ranks Test was applied, as the data were not normally distributed, making a non-parametric approach more appropriate [38]. The results of the test, as presented in **Table 3**, show that the Asymp. Sig. (2-tailed) values for all three classes were 0.00 or less than 0.05. This indicates that there were significant differences between pretest and posttest scores, reflecting an improvement in students' critical thinking skills.

Based on **Figure 3**, all critical thinking indicators showed improvement. The highest posttest scores were found in the interpretation indicator, while the lowest were observed in the inference indicator. Across all classes, interpretation consistently achieved the highest scores, whereas evaluation remained the lowest-performing indicator. Overall, students' pretest scores were lower than their posttest scores, indicating that the learning intervention contributed to the enhancement of critical thinking skills across all assessed indicators, including interpretation, analysis, inference, and evaluation.

As shown in **Figure 4**, students were required to understand and express their opinions regarding the given problems; however, their pretest responses did not adequately reflect these expectations. This finding is consistent with previous research by some papers [3], which indicates that students often struggle to provide reasoned explanations, such as explaining the causes of drought based on their own understanding.

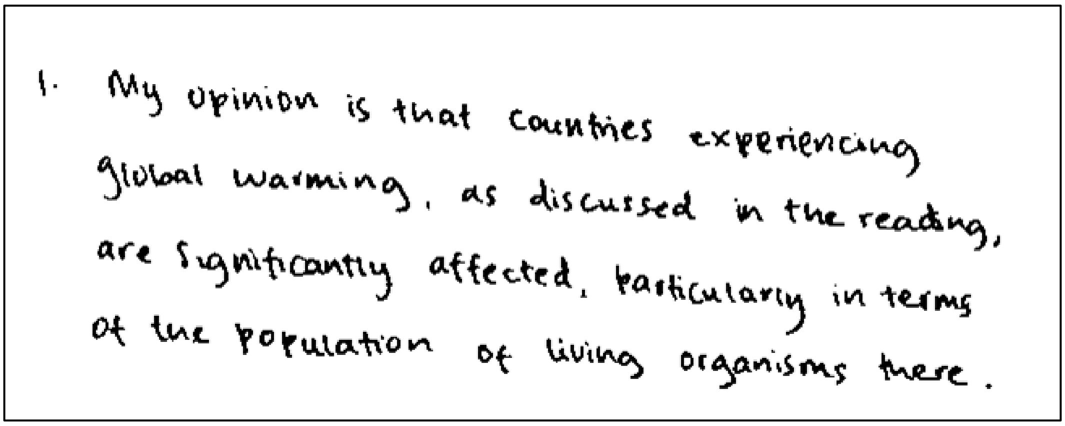


Figure 4. Students' Pretest Responses on the Interpretation Indicator.

In contrast, **Figure 5** demonstrates that students were able to understand the given problems, express their opinions, and provide clear reasoning to support their responses. This finding aligns with previous research by some papers [39], which states that the ability to express reasoned opinions plays an important role in both validating arguments and solving problems.

As shown in **Figure 6**, students were required to analyze and identify the factors causing the presented problems; however, their pretest responses were largely incorrect. This finding is consistent with previous research, which indicates that students often encounter difficulties in focusing on relevant information when analyzing problems.

As shown in **Figure 7**, students were able to analyze and identify the factors causing the presented problems. Their responses reflect improved analytical skills and are consistent with previous research by some papers [40], which emphasizes that students' analytical abilities are closely related to their capacity for logical reasoning.

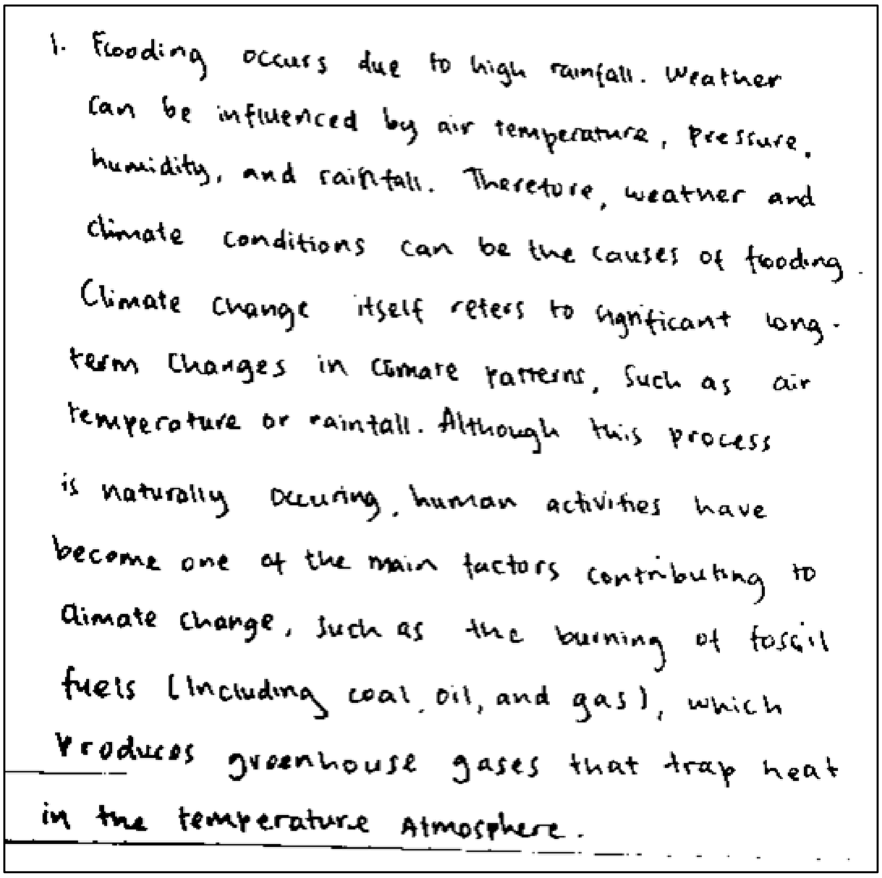

1. Flooding occurs due to high rainfall. Weather can be influenced by air temperature, pressure, humidity, and rainfall. Theretore, weatner and climate conditions can be the causes of flooding. Climate change itself refers to significant long-term changes in climare patterns, such as air temperature or raintall. Although this process is naturally occuring, human activities have become one of the main factors contributing to climate change, such as the burning of fossil fuels (Including coal, oil, and gas), which produces greenhouse gases that trap heat in the temperature Atmosphere.

Figure 5. Students' posttest responses on the interpretation indicator.

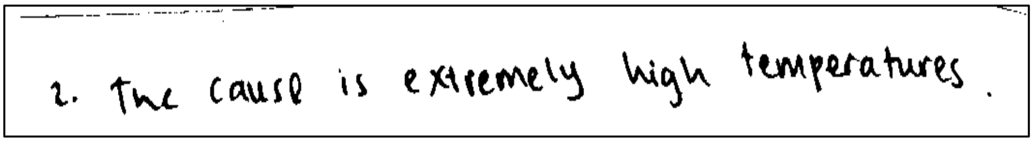

2. The cause is extremely high temperatures.

Figure 6. Students' pretest responses on the analysis indicator.

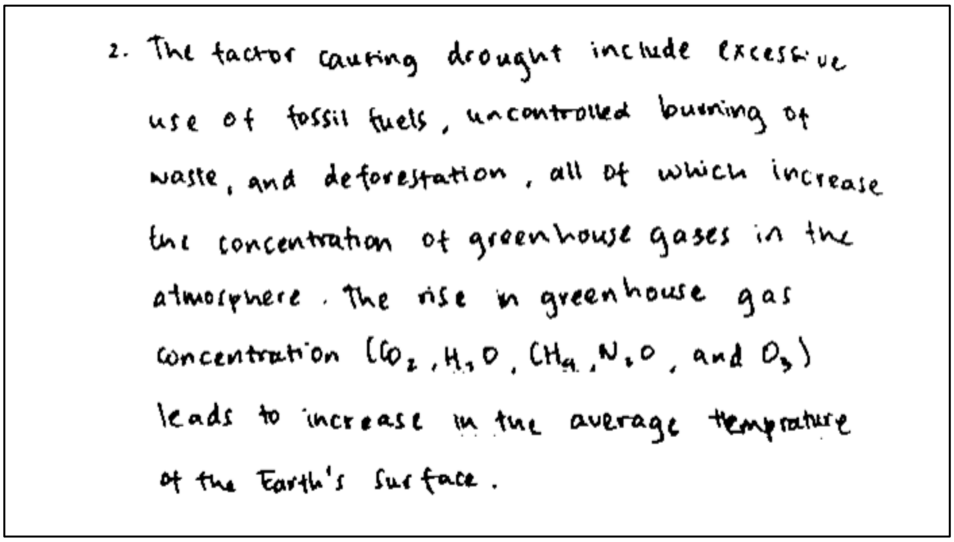

2. The factor causing drought include excessive use of fossil fuels, uncontrolled burning of waste, and deforestation, all of which increase the concentration of greenhouse gases in the atmosphere. The rise in greenhouse gas concentration (CO_2, H_2O, CH_4, N_2O, and O_3) leads to increase in the average temprature of the Earth's surface.

Figure 7. Students' posttest responses on the analysis indicator.

As shown in **Figure 8**, students were required to identify the causes of the problem and describe a proposed solution design; however, their pretest responses were incorrect in both aspects. This finding is consistent with previous research by some papers [41], which indicates that students often experience difficulties in formulating ideas as authentic solutions to a problem.

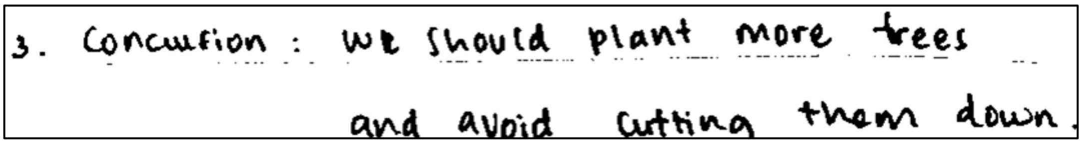

3. Concuufion : we should plant more trees and avoid cutting them down.

Figure 8. Students' pretest responses on the inference indicator.

Figures 9 and **10** show that students were able to identify the causes of the problem and describe solution designs, such as poster-based ideas, as responses to the problem. This finding is consistent with previous research by some papers [42], which highlights that designing solution ideas can support students in understanding problems and facilitate the problem-solving process.

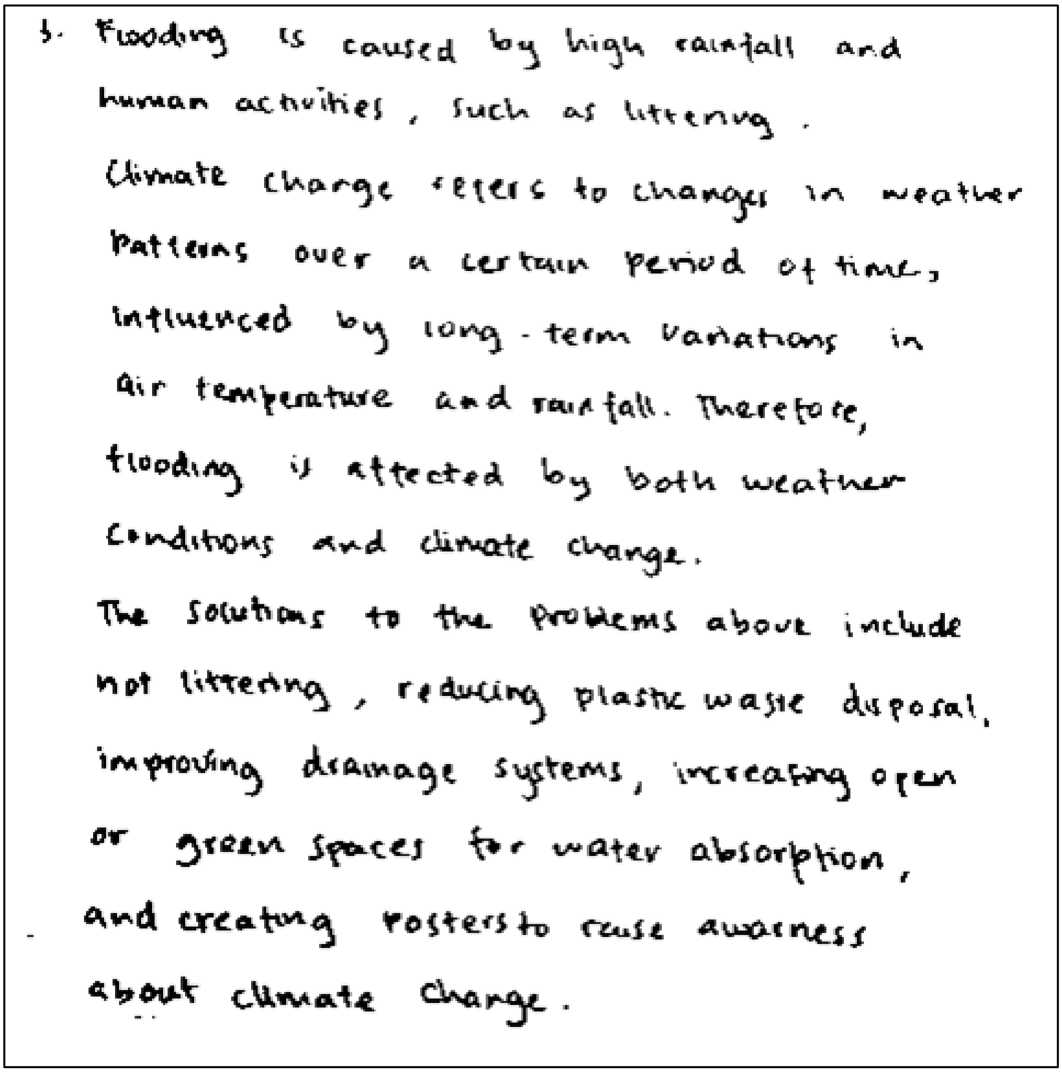

3. Flooding is caused by high rainfall and human activities, such as littering. Climate change refers to changes in weather patterns over a certain period of time, influenced by long-term variations in air temperature and rainfall. Therefore, flooding is affected by both weather conditions and climate change. The solutions to the problems above include not littering, reducing plastic waste disposal, improving drainage systems, increasing open or green spaces for water absorption, and creating posters to raise awareness about climate change.

Figure 9. Students' posttest responses on the inference indicator.

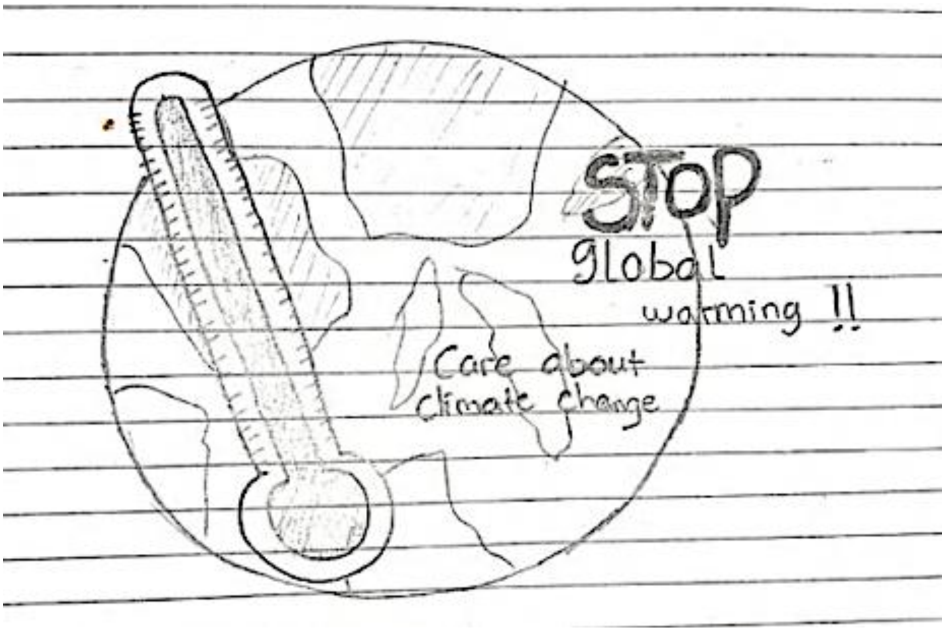
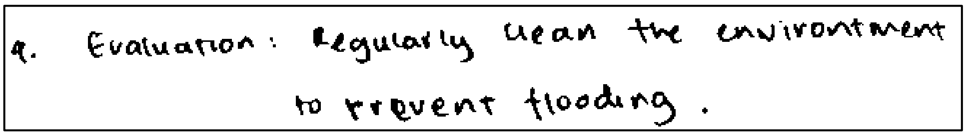


Figure 10. Design of students' posttest response ideas on the inference indicator.

As shown in **Figure 11**, students were required to evaluate or reconstruct problem-solving steps; however, their pretest responses were not accurate in performing this task. In contrast, the posttest responses indicate an improvement in scores across all critical thinking indicators, including interpretation, analysis, inference, and evaluation. This finding is consistent with previous research [41], which emphasizes that students' ability to evaluate ideas involves the use of logical reasoning to reconsider and refine their answers.



4. Evaluation : Regularly clean the environment to prevent flooding .

Figure 11. Students' pretest responses on the evaluation indicator.

Figure 12 shows that students were able to evaluate and reconstruct the steps required to solve the given problems. This finding is consistent with previous research by some papers [3], which indicates that students evaluate problems by considering the conclusions they have drawn.

Further analysis was conducted using the N-gain test to determine the level of improvement in students' critical thinking skills. The results, presented in **Table 4**, show that Experimental Class 1 achieved a mean N-gain of 0.66, categorized as medium. In contrast, Experimental Class 2 obtained a mean of 0.17, and the Control Class achieved 0.13, both categorized as low. These findings indicate that the greatest improvement in critical thinking skills was observed in Experimental Class 1, which implemented the PBL model assisted by PhyPo.

The subsequent analysis presents Cohen's d as a measure of effect size to determine the magnitude of differences between groups. The results of the effect size analysis are presented in **Table 5**. The comparison between Experimental Class 1 and Experimental Class 2 showed a medium effect size (d = 0.77). Similarly, the comparison between Experimental Class 1 and the Control Class also indicated a medium effect size (d = 0.53). In contrast, the comparison between Experimental Class 2 and the Control Class showed a very low effect size (d = 0.11).

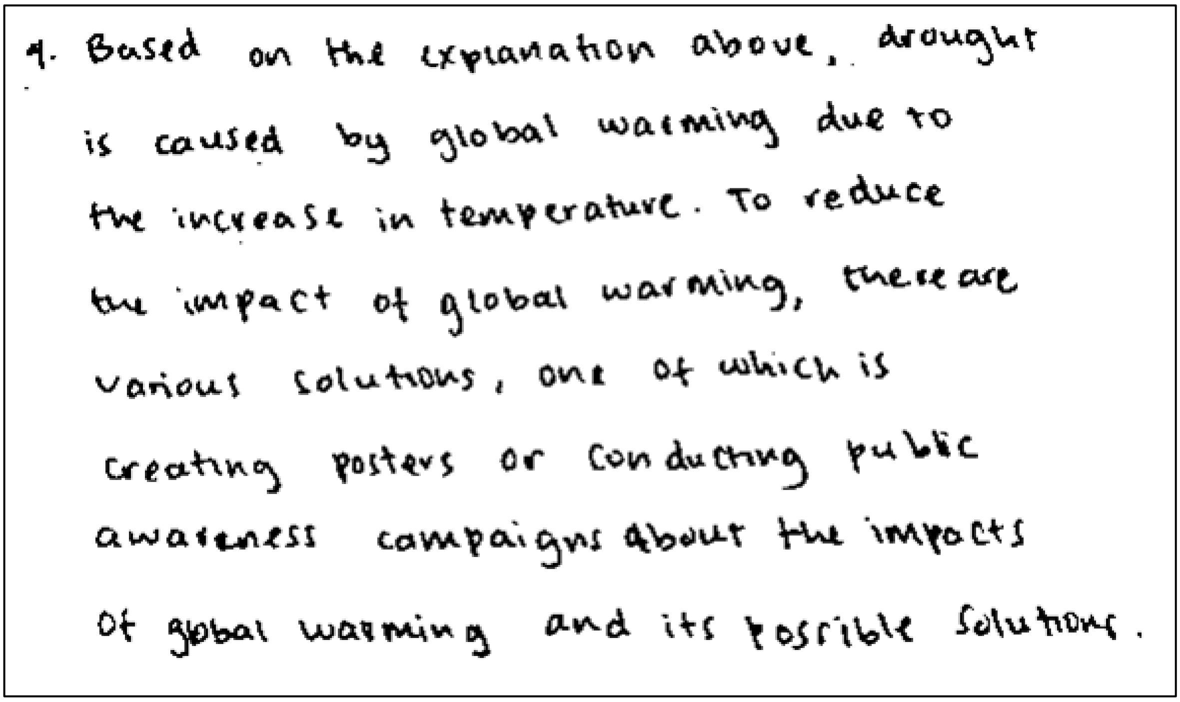

9. Based on the explanation above, drought is caused by global warming due to the increase in temperature. To reduce the impact of global warming, there are various solutions, one of which is creating posters or conducting public awareness campaigns about the impacts of global warming and its possible solutions.

Figure 12. Students' posttest responses on the evaluation indicator.

These findings suggest that the implementation of the PBL model assisted by PhyPo produced a greater impact on students' critical thinking skills compared to both the PBL model without PhyPo and conventional learning. Therefore, it can be concluded that integrating the PBL model with digital pocketbook media is more effective in improving students' critical thinking skills.

4.1.4. Student responses

Student responses were collected through a questionnaire administered via Google Forms, with the results summarized in **Table 6**. The questionnaire consisted of 10 statements measured using a four-point Likert scale and was validated before administration, showing high validity and reliability [43]. Students' responses toward the implementation of PBL assisted by PhyPo were generally positive. The majority of students in Experimental Class 1 selected "agree" and "strongly agree" for statements indicating that PhyPo was enjoyable and supported their learning process. Similar positive trends were also observed in Experimental Class 2 and the control class. More than 80.00% of students across groups agreed that PBL assisted by PhyPo improved their critical thinking skills. Additionally, most students expressed interest in using PhyPo in future physics learning, indicating that the integration of PBL and PhyPo was perceived as both beneficial and engaging.

Students' responses to the implemented learning model were categorized as very good. Although initial responses indicated that physics was perceived as a boring subject, consistent with previous findings by some papers [3], the implementation of PBL assisted by digital pocketbooks resulted in more positive perceptions, with 71.43% of students agreeing that learning physics became enjoyable. Furthermore, students showed interest in using PhyPo in future learning, with positive responses recorded across all classes. These findings suggest that the use of innovative learning models and digital media not only enhances students' engagement but also supports the development of their critical thinking skills.

Table 6. Students' responses to the implementation of PBL Assisted by PhyPo.

STATEMENTS	EXPERIMENT 1 (%) (N=35)				EXPERIMENT 2 (%) (N=35)				CONTROL (%) (N=35)			
	1	2	3	4	1	2	3	4	1	2	3	4
Physics is a boring subject	8.57 (3)	31.43 (11)	51.43 (18)	8.57 (3)	17.14 (6)	40.00 (14)	4286 (15)	0.00 (0)	8.57 (3)	25.71 (9)	48.57 (17)	17.14 (6)
Physics is a difficult subject	2.86 (1)	11.43 (4)	71.43 (25)	14.29 (5)	5.71 (2)	14.29 (5)	57.14 (20)	22.86 (8)	0.00 (0)	11.43 (4)	45.71 (16)	42.86 (15)
Global warming material is not important to learn.	54.29 (19)	40.00 (14)	5.71 (2)	0.00 (0)	68.57 (24)	28.57 (10)	2.86 (1)	0.00 (0)	57.14 (20)	37.14 (13)	5.71 (2)	0.00 (0)
Global warming material is difficult to learn	17.14 (6)	42.86 (15)	34.29 (12)	5.71 (2)	22.86 (2)	48.57 (17)	28.57 (10)	0.00 (0)	11.43 (4)	37.14 (13)	48.57 (17)	2.86 (1)
Learning global warming using the PBL model is boring.	34.29 (12)	57.14 (20)	5.71 (2)	2.86 (1)	22.86 (8)	54.29 (19)	22.86 (8)	0.00 (0)	31.43 (11)	45.71 (16)	20.00 (7)	2.86 (1)
Learning global warming using PhyPo is enjoyable.	2.86 (1)	5.71 (2)	71.43 (25)	20.00 (7)	8.57 (3)	20.00 (7)	60.00 (21)	11.43 (4)	2.86 (1)	5.71 (2)	68.57 (24)	22.86 (8)
The use of PBL assisted by PhyPo in learning global warming is enjoyable	2.86 (1)	5.71 (2)	71.43 (25)	20.00 (7)	2.86 (1)	17.14 (6)	65.71 (23)	14.29 (5)	2.86 (1)	20.00 (7)	42.86 (15)	34.29 (12)
Critical thinking skills are important in physics learning	0.00 (0)	8.57 (3)	60.00 (21)	31.43 (11)	2.86 (1)	2.86 (1)	48.57 (17)	45.71 (16)	0.00 (0)	0.00 (0)	48.57 (17)	51.43 (18)
The use of PBL assisted by PhyPo can improve critical thinking skills in learning global warming	2.86 (1)	5.71 (2)	77.14 (27)	14.29 (5)	2.86 (1)	14.29 (5)	65.71 (23)	17.14 (6)	2.86 (1)	8.57 (3)	71.43 (25)	17.14 (6)
I am interested in using PhyPo in physics learning	2.86 (1)	8.57 (3)	57.14 (20)	31.43 (35)	2.86 (1)	14.29 (5)	65.71 (23)	17.14 (6)	5.71 (2)	5.71 (2)	51.43 (18)	37.14 (13)

4.2. Bibliometric Trends and Implications for Sustainable Development Goals

A bibliometric analysis was conducted to examine global research trends related to Problem-Based Learning (PBL), as illustrated in **Figure 13**. The data show a substantial and continuous increase in the number of publications over time, particularly after the early 2000s, with a sharp rise in recent years. This exponential growth indicates that PBL has become a major focus in educational research, driven by the increasing demand for student-centered learning approaches that promote higher-order thinking skills. The rapid expansion of publications also reflects the growing integration of digital technologies in education, especially in response to the need for flexible and interactive learning environments.

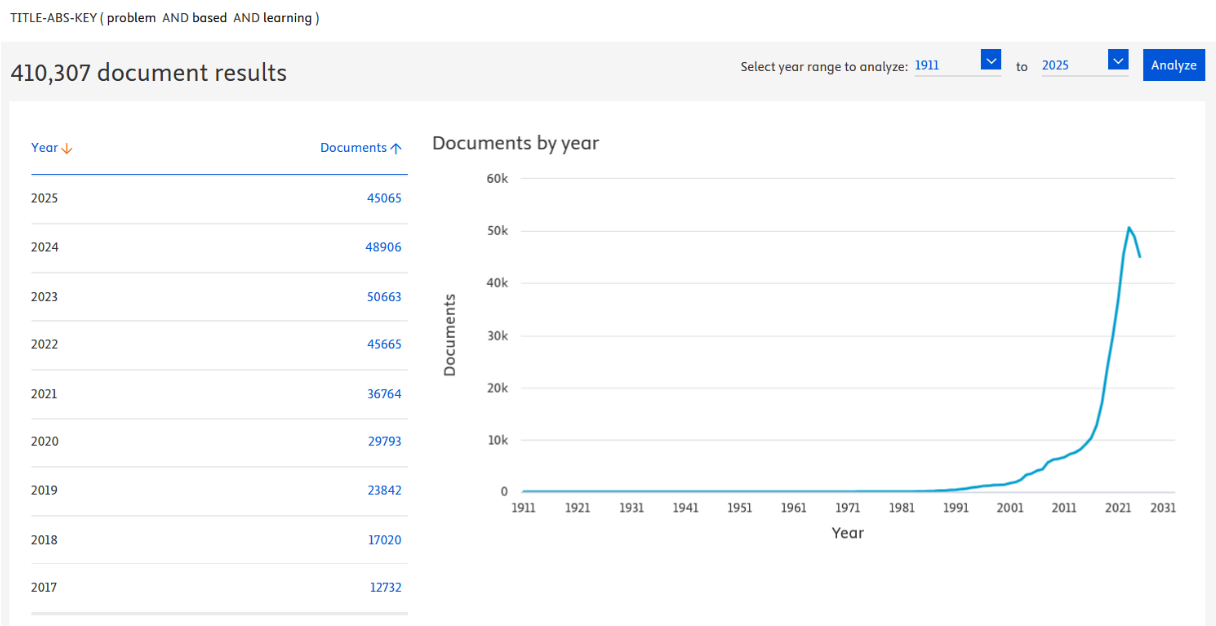


Figure 13. Bibliometric analysis of global research trends in problem-based learning based on TITLE-ABS-KEY query, showing the annual number of publications over time. Data were obtained from the Scopus database in April 2026**.**

The significant upward trend suggests that PBL is widely recognized as an effective pedagogical approach for improving critical thinking, problem-solving, and collaborative skills. However, despite the large number of studies, the integration of PBL with digital learning media, such as digital pocketbooks, remains relatively underexplored. This observation highlights a research gap in combining interactive digital tools with inquiry-based learning models to maximize student engagement and learning outcomes. Therefore, the present study contributes by integrating PBL with a Physics Digital Pocket Book (PhyPo), offering a novel approach within this rapidly growing research domain.

From a sustainability perspective, the increasing research trend in PBL aligns closely with several SDGs. In particular, SDG 4 (Quality Education) is addressed through the development of innovative and student-centered learning strategies that enhance critical thinking skills. Furthermore, the integration of digital learning media supports SDG 9 (Industry, Innovation, and Infrastructure) by promoting the use of technology in education. In addition, the application of PBL in global warming materials contributes to SDG 13 (Climate Action) by fostering students' awareness and understanding of environmental issues.

The bibliometric findings demonstrate that PBL-based learning continues to evolve as a key educational approach with strong relevance to global sustainability goals. The integration of digital media, as proposed in this study, provides a strategic direction for advancing innovative, technology-enhanced, and sustainable learning environments.

5. CONCLUSION

This study presents a bibliometric and experimental investigation of the implementation of Problem-Based Learning assisted by a PhyPo in enhancing students' critical thinking skills. The findings demonstrate that the integration of digital learning media with problem-based approaches effectively improves student engagement, learning outcomes, and critical thinking abilities. Bibliometric insights confirm the growing importance of combining digital tools with active learning strategies, while highlighting the limited integration of these approaches in physics education. The novelty of this study lies in the combined application of PBL and digital pocketbooks within a unified learning framework. This approach contributes to SDGs, particularly quality education and digital innovation in learning environments.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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