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Integrating Digital Books, 3D Animations, and Online Problem-based Learning to Improve Pre-service Teachers' Scientific Literacy in General Physics Course

Titin Sunarti [1,a,*], Muhammad Satriawan [1,b], Binar Kurnia Prahani [1,c], and Iqbal Ainur Rizki [2,d]

[1] Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya
Jalan Ketintang, Surabaya 60231, Indonesia
[2] School of Education, Victoria University of Wellington
21 Kelburn Parade, Kelburn, Wellington 6012, New Zealand

e-mail: [a] titinsunarti@unesa.ac.id, [b] muhammadsatriawan@unesa.ac.id, [c] binarprahani@unesa.ac.id, and [d] iqbalainur19004@gmail.com
* Corresponding Author

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Abstract

Some literature suggests that the low scientific literacy of pre-service teachers (PSTs) should be considered when designing teaching strategies. To address this issue, digital books with 3D animation, representing advanced developments in digital technology, can be integrated into an online Problem-Based Learning (PBL) model. Consequently, this study aimed to test the effectiveness of the Digital Books, 3D animation, and PBL (DBAPBL) model in enhancing the scientific literacy of PSTs. The research method employed was quantitative, utilizing a quasi-experimental design. The sample comprised 67 pre-service biology teachers enrolled in the General Physics course. Data collection technique utilised pre- and post-test along with survey in the last teaching session. Then, the data was analysed descriptively and statistically using t-test. The findings revealed that the DBAPBL model led to PSTs achieving a science literacy score above 89.5 or in the high category. Statistical test results also indicated a significant difference between scientific literacy's pre- and post-test results, affirming the model's effectiveness. Another noteworthy finding suggests that PSTs have a tendency to respond positively to the DBPAPBL model. This research implies a pedagogical innovation in physics education and advocates for updating curriculum guidelines related to the DBAPBL model, thereby contributing to the improvement of Indonesia's PISA scores.

Keywords: *Digital Book; 3D Animations; Problem-Based Learning; Scientific Literacy*

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INTRODUCTION

Scientific literacy is a crucial facet that can serve as a preparation for pre-service teachers (PSTs) to confront the ever-advancing landscape of technology, particularly in terms of accessing information [1,2]. Bond asserts that individuals equipped with the knowledge to comprehend scientific facts and understand the intricate relationship between science, technology, and society, and who can apply this knowledge to solve real-life problems, are deemed scientifically literate [3]. In alignment with this perspective, DeBoer [4] emphasizes the importance of scientific literacy by highlighting that educating the public to attain scientific literacy is the central objective of every science education reform.

In the context of general physics courses, scientific literacy empowers individuals to make informed decisions, particularly in areas where physics plays a significant role. This involves critically evaluating information, distinguishing between evidence-based claims and pseudoscience, and applying scientific reasoning to real-world situations [5,6]. For example, in the topic of energy choices, a scientifically literate individual can assess different energy sources, understand their environmental impact, and make informed decisions about sustainable and responsible energy consumption [7]. Thus, informed decision-making extends beyond personal choices to societal issues. A scientifically literate population is better equipped to engage in discussions and decision-making processes related to policy issues, environmental conservation, and technological advancements [8].

PSTs in the physics course encounter dual challenges: being individual members of society in the era of Industry 4.0 with new literacy demands, and concurrently preparing for their roles as future physics educators. In the context of Industry 4.0, characterized by rapid advancements in technology and information, the educational landscape is evolving swiftly [9,10]. This is evidenced by the proliferation of advanced technology applications designed to cater to essential human needs. In this era of Industry 4.0 with new science and literacy, the significance of education is escalating to ensure that students not only acquire essential skills and innovation but also develop proficiency in utilizing technology and information media [11]. The ultimate goal is to equip PSTs with the capabilities to effectively navigate a world where these skills are imperative for both work and survival.

PSTs often bear the responsibility of addressing issues stemming from the Program for International Student Assessment (PISA) test results. These results reveal a significant challenge, as the scientific literacy scores of Indonesian students have consistently lagged behind those of their counterparts from other countries participating in the PISA program [12–14]. Despite the duration spanning from 2000 to 2018, there has been no notable progress in the scientific literacy scores of Indonesian students. In the 2018 PISA assessment, while the average score for science among OECD member countries was 489, Indonesian students recorded a further decline, reaching a score of 396 [15]. Previous research also affirmed that the scientific literacy profile of PSTs remains categorized as low [16–19]. Consequently, as a PST, embracing this challenge and enhancing preparedness is imperative.

Conversely, the Problem-Based Learning (PBL) model emerges as a pedagogical approach that holds promise in addressing this challenge [20,21]. PBL engages learners in real-world problems, requiring them to synthesize information, assess its logic and validity within a specific context, and subsequently apply this knowledge to solve problems for a more profound understanding [22,23]. Parno et al. [5] highlighted that the PBL model can effectively cultivate scientific literacy skills through investigative and analytical activities. Moreover, anchoring the learning process in social scientific problems positively impacts various facets of scientific literacy competence. Additionally, PBL presents PSTs with authentic, real-world problems related to scientific concepts. This contextualization helps them see the practical relevance of scientific knowledge, making the learning experience more meaningful [24]. Meanwhile, due primarily to technological developments such as distance learning, mobile learning, and e-learning, the PBL model can be implemented online [25].

In the online PBL model, technological intervention is crucial to support the implementation of learning processes [25]. One innovative form of technological intervention involves transforming traditional textbooks into digital books. According to Kusumawati et al. [26], a digital book is a digital rendition of a book that contains digital information in the form of text, images, and audio packaged in a file. E-books offer enhanced interactivity compared to conventional books. For example, learners can instantly search for keywords they need. This technology also allows users to incorporate interactive visualizations, including 3D animations [27]. Consequently, students can more easily understand abstract and microscopic physics concepts like optics, modern physics, magnetic fields, and thermodynamics. The integration of digital books incorporating 3D animation proves highly suitable for supporting the online PBL process, fostering increased PSTs' scientific literacy. Prahani et al. [28] found that adding 3D digital books into online PBL could effectively enhance high school students' problem-solving skills in physics education. Nevertheless, there has been no research that simultaneously integrates the online PBL model, digital books, and 3D animations to enhance the scientific literacy of PSTs.

Previous research showed that the implementation of the PBL model could effectively enhance PSTs' physics concept understanding [29], critical thinking skills [20], metacognitive skills [30], mathematical representation [31], collaborative [32], as well as scientific literacy [33]. Meanwhile, the use of digital books has been proven empirically to train students' physics conceptual mastery [34], creative thinking skills [35], critical thinking, and literacy skills [36]. Additionally, utilizing 3D animations in physics learning could fruitfully enhance students' learning achievement [37], thinking skills in abstract concepts [38], self-efficacy, and conceptions of learning [39]. Therefore, this study integrates those three technologies to improve PSTs' science literacy because they can provide interactive visualizations of complex concepts, engaging students in real-world problem-solving, and enhancing their digital skills simultaneously. This novel approach distinguishes the current research from previous studies.

The primary objective of this research is to assess the effectiveness of a physics learning approach that integrates digital books, 3D animations, and the online PBL (DBAPBL) model in enhancing the scientific literacy of PSTs. Additionally, the research aims to explore the responses of PSTs to the DBAPBL model following their participation in the learning process. This research is envisaged contributing to the improvement of PISA scores in Indonesia by introducing a learning model specifically designed to enhance scientific literacy through the incorporation of digital technology.

METHOD

Research Design

This research design is quantitative with a quasi-experimental type with a one-group pre-test post-test design [40], as presented in Figure 1. The study involved two classes with similar treatment using the DBAPBL model. The research subjects were 67 undergraduate students from the Department of Biology Education who took the General Physics course. One class (PBB = Biology Education Class of B) consisted of 34 students, while the other one (PBC = Biology

Education Class of C) was 33 students. This research was conducted from September to November 2023 at Universitas Negeri Surabaya. The sampling technique used was random cluster sampling because the university randomly chose the class.

Figure 1. Research Design and Process

Instruments

The study's tools include student worksheets, a lesson plan, a digital book application with 3D animation, a syllabus, test instruments for scientific literacy, and students' response questionnaire. Five syntaxes (problem orientation, student organization, group investigation guidance, creation and presentation of works and exhibitions, analysis and evaluation of the problem-solving process, and creation and presentation of exhibitions) were used to implement the BDAPBL model in both classes [41]. Three-dimensional animation was used in conjunction with digital books in each of these syntaxes. For both classes, all of the learning exercises were completed online using various auxiliary tools, including Google Meet and WhatsApp. The 47 MB digital book was large. The application can be used offline for online learning to cut down on network usage. Figure 2 witnesses several features of the digital book.

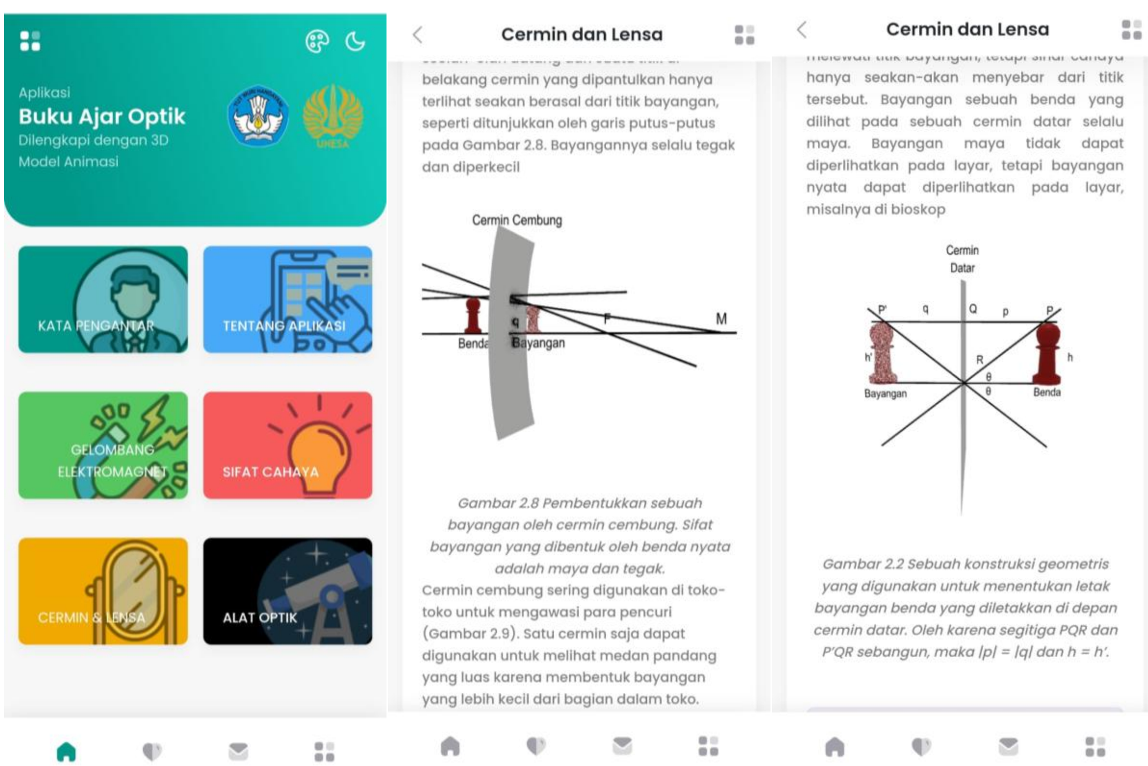

Figure 2. Some Display of the Digital Book With 3D Animation Features

Worksheets are another instrument used by PSTs to help them learn. They facilitate their understanding of the material by aligning it with the online PBL learning syntax. In the meantime, there are two kinds of scientific literacy test instruments: pre- and post-test, which include scientific literacy indicators. Further explanation of the test instruments is illustrated in Table 1. Lastly, the PSTs response questionnaire consisted of several sections: learning instruments, novelty, usability, future direction, fruitfulness, interest in worksheets, learning environment, and use of digital books. These aspects were measured using a Likert scale of 1-5.

Table 1. Scientific Literacy Test and Its Question Sample

Scientific Literacy Indicator	Question Total	Question Example
Elucidating scientific phenomena	4	Anggi is riding her motorbike and sees something behind her. Anggi uses the rear view mirror to look behind her. What type of mirror does she use on her motorbike? Why does she use that mirror?
Interpreting scientific evidence and data	2	The image below shows some of the visible spectrum of electromagnetic waves ranging from gamma rays to radio waves. [*Image not shown due to copyright protection*] Arrange the frequencies of the electromagnetic waves from largest to smallest as evidenced by writing the wavelength and completing the mathematical equation for each one.
Assessing and formulating scientific research plans	4	One day, William and his family went on holiday to Big Bend National Park, Texas. Then, he found a rare butterfly with transparent wings that has the scientific name Greta oto. He wanted to take a picture of the butterfly to add to his collection, but he was afraid it would fly away. If you were William's brother, what advice would you give to William so that the butterfly doesn't fly away, but the photos are still sharp?

Noteworthy, all instruments have been assessed for validity. The validity test results show that the average score obtained is 3.61 or has very valid criteria. Meanwhile, reliability testing shows that each instrument has a Cronbach alpha value ≥ 0.7, indicating their reliable functionality. Thus, the research instruments are feasible to be implemented.

Data Collection

Pre- and post-test results can be used to analyze the effectiveness of learning models through PSTs' scientific literacy. The homogeneity test showed that the initial scientific literacy scores were homogeneous across all samples. Initially, a pre-test was administered to PSTs in both classes to determine their baseline scores in scientific literacy. Following that, a DBAPBL model was used to provide learning treatment for both classes. A post-test was given to both classes at the conclusion of the lesson to ascertain their final levels of scientific literacy. Additionally, they supplied questionnaires for PSTs responses. The test's questions were scientific literacy questions that align with the 2019 OECD guidelines for scientific literacy assessments [15], which include three indicators: explaining phenomena scientifically; interpreting data and scientific evidence; and evaluating and designing scientific investigations.

Data Analysis

Adapting Prahani et al.'s effectiveness of a learning model [42], the DBAPBL model could be said effective if: 1) science literacy scores are in the medium category, 2) N-gain scores have medium criteria, and 3) there are significant differences between pre- and post-test scientific literacy results. The determination of statistical significance is using the t-test inferential statistics. Meanwhile, PSTs response criteria is also determined by measuring their positiveness using the following formula: (score obtained/score maximum) ×100%. The determination of scientific literacy, N-gain scores, and PST responses are shown in Table 2.

Table 2. Scientific Literacy, N-gain, and PSTs Response Criteria [43,44]

Scientific Literacy		**N-Gain**		**PSTs' Response**	
$L \leq 57$	Low	$g < 0.3$	Low	1 – 25%	Not Positive
$57 < L \leq 71$	Medium	$0.3 \leq g < 0.7$	Medium	26 – 49%	Less Positive
$71 < L \leq 100$	High	$g \geq 0.7$	High	51 – 74%	Positive
				76 – 100%	Very Positive

RESULTS AND DISCUSSION

DBAPBL Model Effectiveness

Figure 3 shows the graph of scientific literacy scores in both classes, which in the pre-test had scores in the low criteria. After both classes experienced the DBAPBL model, their scientific literacy scores increased significantly to high criteria. This comprises the DBAPBL model successfully fulfilling the first effectiveness criterion, that the final science literacy score obtained by PSTs has high criteria.

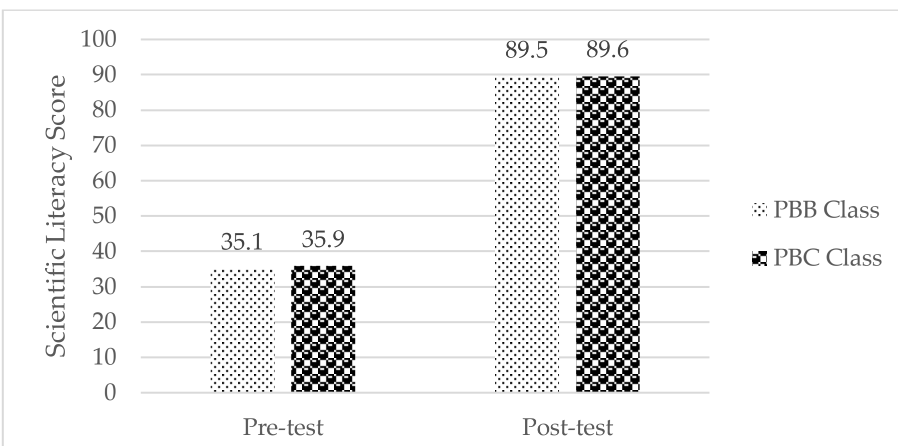

Figure 3. PSTs' Pre- and Post-Test Scientific Literacy Score

The data analysis indicates a significant and statistically substantial improvement in the scientific literacy of PSTs who experienced the DBAPBL model (Table 2). Both classes, PBB and PBC, displayed high N-gain values, denoting a considerable enhancement in understanding scientific literacy. The remarkably high t-values and significant p-values reinforce the robustness of these findings, emphasizing that the observed improvements are not due to chance. Achieving the "High" score criteria of scientific literacy in both classes underscores the consistently positive impact of the DBAPBL model on PSTs' scientific literacy.

Table 3. Analyzing PSTs' Scientific Literacy Criteria and Paired T-Test

Class	N	N-gain		t-value	p (Sig.)
		Score	Criteria		
PBB	34	0.846	High	46.82	0.00*
PBC	33	0.849	High	52.38	0.00*

Note: Range score for N-gain is 0 ≤ N ≤ 1

The N-gain analysis across specific scientific literacy indicators for PSTs in both PBB and PBC classes highlights consistent and substantial improvements, as presented in Table 4. N-gain values are notably high in each scientific literacy indicator, all categorized as "High." This suggests that the integration of digital books, 3D animations, and the online PBL model effectively enhances PSTs' skills in explaining scientific phenomena, interpreting data, and evaluating and designing scientific investigations. In addition, the results also show that the distribution of improvement in each indicator tends to be even, thereby, there is no disparity in the improvement of each scientific literacy indicator. The uniformity of these positive outcomes across diverse scientific literacy dimensions reinforces the robustness and comprehensiveness of the DBAPBL model in fostering a well-rounded scientific literacy among PSTs in the General Physics course.

Table 4. N-gain Analysis of PSTs' Scientific Literacy on Each Indicator

Class	N	Scientific Literacy Indicators					
		Explaining Phenomena Scientifically		Interpreting Data and Scientific Evidence		Evaluating and Designing Scientific Investigations	
PBB	34	0.83	High	0.86	High	0.83	High
PBC	33	0.83	High	0.85	High	0.84	High

Note: Range score for N-gain is 0 ≤ N ≤ 1

The effective indication of the DBAPBL model is very reasonable. First and foremost, the integration of digital books allows for a more dynamic and interactive learning experience [45]. Digital books provide not only textual information but also incorporate multimedia elements such as images and interactive 3D animations. This multimedia approach addresses different learning styles and facilitates a deeper understanding of abstract scientific concepts, particularly those related to optics, modern physics, magnetic fields, and thermodynamics in the General Physics course. The 3D animations, in particular, play a crucial role in visualizing complex phenomena, making it easier for PSTs to comprehend and apply theoretical knowledge [46]. The results align with the research conducted by Ahied et al. [47], which suggests that integrating 3D animation-based media into online learning can enhance scientific literacy. Technology in education (like digital books) has the potential to replace the roles of teachers and students by guiding, questioning, and assisting students in creating their own knowledge [45]. In order to become deep learners, PSTs are more proactive and adaptive in their quest for information [20].

The integration of digital books with 3D animation is supported by the technology acceptance model (TAM) theory. TAM focuses on the factors influencing the acceptance and use of technology [48,49]. When it comes to digital books, ease of use, perceived usefulness, and accessibility are key elements. The integration of digital books in education is supported by the TAM, as it offers a user-friendly and convenient platform for accessing educational content. PSTs tend to enjoy undergoing the learning process using digital book technology, thereby they feel that this technology is very helpful in the scientific literacy learning process. Additionally, the multimodal learning theory reinforces the incorporation of digital book utilization in learning by recognizing that individuals have diverse learning preferences and that presenting information through multiple modes (such as text, images, audio, and video) can enhance comprehension and retention [50,51]. Digital books, with their ability to integrate various media formats, cater to multimodal learning preferences. By providing diverse representations of scientific concepts, including interactive 3D animations, images, and textual explanations, digital books cater to different learning preferences. This approach fosters a more holistic understanding of complex scientific phenomena, helping PSTs grasp abstract concepts and apply them in real-world contexts [52].

Furthermore, adopting an online PBL approach adds an additional layer of effectiveness to the model. This is because online PBL introduces real-world problems that require the application of scientific principles [19,41,53]. This contextualization helps PSTs see the relevance of scientific concepts in practical scenarios. By addressing authentic problems, PSTs gain a deeper understanding of how scientific literacy is essential for problem-solving in various contexts. When PSTs in the problem-solving phase, as mentioned in the online PBL syntax, they require active engagement, collaboration, and critical thinking. PSTs are not passive recipients of information; instead, they become active participants in the learning process [54]. This approach cultivates problem-solving skills, analytical thinking, and the ability to critically evaluate and apply scientific information—a fundamental aspect of scientific literacy. Additionally, the online nature of PBL aligns with the technological advancements characterizing the current educational landscape, preparing PSTs to navigate and leverage digital tools effectively in their future teaching practices [55]. These results align with several empirical findings that suggest increasing students' scientific literacy through the use of PBL models [33,56,57]. Another foundation of PBL is Piaget's cognitive constructivism learning theory. Students can actively build their own knowledge through PBL by connecting to their environment through the processes of assimilating and adapting [58].

The N-gain analysis across specific scientific literacy indicators further underscores the effectiveness of the DBAPBL model. The consistent "High" categorization across scientific literacy indicators (i.e., Explaining Phenomena Scientifically, Interpreting Data and Scientific Evidence, and Evaluating and Designing Scientific Investigations) demonstrates the model's versatility in addressing various dimensions of scientific literacy. The significant improvement in these specific skills indicates that the DBAPBL model not only imparts each scientific literacy indicator but also enhances all of the practical crucial for effective scientific literacy teaching. As PSTs work together to address problems, they actively contribute to each other's understanding of different scientific literacy indicators [15]. That is why this collective engagement ensures a holistic improvement in their overall scientific literacy profile.

Pre-service Teachers Response

Table 5 indicates favorable responses from the PSTs across various aspects of the DBAPBL model. Notably, the responses reflect high levels of attractiveness, both in terms of learning instruments and learning activities. The positive novelty and understanding ratings suggest that the PSTs perceive the DBAPBL model as innovative and practical in facilitating their comprehension of General Physics content. However, the instruments' novelty shows the lowest score among other aspects, possibly because they think that online learning through a problem-solving process is common, especially due to the Covid-19 pandemic. Even though the score is marginal, most PSTs responded positively to the novelty of the learning process because of the intervention of digital technology and PBL. Additionally, the positive responses regarding the prospect, expendability, and peer-cooperativeness aspects highlight the model's perceived value and collaborative nature. Lastly, the very positive rating for digital book interestingness underscores the effectiveness of incorporating digital books, 3D animations, and online PBL in capturing the interest and scientific literacy of PSTs.

Table 5. PSTs Response Against DBAPBL Model

Aspect	Score (%)	Criteria
Learning Instruments Attractiveness	76.42	Very Positive
Learning Instruments Novelty	56.72	Positive
Learning Instruments Understanding	68.66	Positive
Learning Instruments Prospect	70.75	Positive
Learning Instruments Expendability	71.64	Positive
Learning Activity Attractiveness	74.93	Positive
Peer Cooperativeness	77.01	Very Positive
Digital Book Interestingness	78.21	Very Positive

The high ratings for attractiveness, interestingness, and very positive responses towards the digital book component suggest that the DBAPBL model captures the interest of PSTs. The appeal is likely attributed to the interactive nature of digital books and the incorporation of engaging 3D animations, creating a visually compelling and immersive learning environment. Thus, this positiveness supports their scientific literacy improvement. What's more, the very positive response towards peer cooperativeness suggests that PSTs value the collaborative learning environment fostered by the DBAPBL model. Collaborative problem-solving activities inherent in PBL and the interactive nature of digital resources contribute to a sense of shared learning, fostering peer support and cooperation. This is supported by Vygotsky's theory of social constructivism, which states that the learning process occurs when there is interaction between students and their smarter peers [41].

This study's results align with several previous studies [59,60], stating that PBL learning models that have positive responses from students have high practicality and effectiveness in physics learning. On the other hand, a study conducted by Luo et al. [61] found that students have a higher acceptance of e-books instead of textual ones. This is because students who have completed e-book use courses offered by libraries have enhanced their familiarity with e-books and their use of e-book software, thereby increasing their literacy, and this familiarity has contributed to their higher acceptance of e-books. The acceptance of e-books among students is considered critical for successful implementation in the context of e-learning platforms [62].

The limitation of this study is that there is no observation of learning implementation, as a result, the level of practicality of the DBAPBL model is unmeasured. Secondly, there is no comparison or control class, so the effectiveness of the DBPAPBL model with the traditional teaching method in improving PSTs' scientific literacy is unknown. Ultimately, the topic was only limited to optical science. As a recommendation, future research may observe the implementation process of the DBPAPBL model and add a control class as a comparison. Future researchers can also develop digital book applications with 3D animation on other materials and complementary features such as augmented reality or virtual reality to further create immersive and interactive learning, improving PSTs' motivation in the General Physics course.

This research has implications for practitioners utilizing the DBAPBL model as a pedagogical innovation in physics education. Integrating digital books, 3D animations, and online PBL offers a dynamic and engaging approach to teaching and learning, aligning with contemporary educational needs. Using multimedia resources, collaborative problem-solving, and interactive learning activities caters to diverse learning styles, enabling practitioners to create inclusive and effective learning environments. Additionally, policymakers may consider integrating the principles of the DBAPBL model into physics education curricula. This may involve updating curriculum guidelines to incorporate digital technologies and PBL methodologies. Recognizing Indonesia's stagnant PISA scores and challenges in scientific literacy, policymakers may view the DBAPBL model as a potential solution.

CONCLUSION

To sum up, the DBAPBL model integrates digital books, 3D animation, and the PBL model in the General Physics course. Based on the results of statistical tests, this learning model demonstrates good effectiveness in enhancing PSTs' scientific literacy by design. Following exposure to the DBPABL model, PSTs exhibited high science literacy scores with a corresponding high N-gain value. Additionally, PSTs responded very positively to the learning instruments, application product, and learning environment, expressing an increased desire for further development of the application product and 3D animation. The key novelty of this study lies in the simultaneous use of 3D animation and digital books integrated with the PBL model. The interactivity of the digital book, combined with the immersiveness of 3D animation, is believed to facilitate PSTs in conducting scientific inquiry activities, thereby improving their scientific literacy.

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AUTHOR CONTRIBUTIONS

Titin Sunarti: Conceptualization, Investigation, and Supervision; Muhammad Satriawan: Methodology, Data Curation; Binar Kurnia Prahani: Project Administration and Validation; and Iqbal Ainur Rizki: Writing - Original Draft and Formal Analysis.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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