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Integration of Problem-Based Learning in Science Learning with Digital Learning to Improve Critical Thinking and Collaboration Skills: A Review

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Abstract: The integration of digital-based Problem-Based Learning (PBL) is increasingly important to support learning that demands critical thinking and collaboration skills in the technological era. This approach allows the exploration and investigation process to be carried out in a more interactive, flexible, and student-centered manner, making it relevant for improving the quality of 21st-century learning. This study aims to explore the forms of digital PBL implementation and its impact on student competencies through a systematic review. The method used is a Systematic Literature Review (SLR) with article searches in Publish or Perish version 8 and Google Scholar, using the keywords "Problem-Based Learning," "digital learning," "critical thinking," and "collaboration" for the period 2020-2025. The selection process followed PRISMA 2020, resulting in 15 articles meeting the inclusion criteria from the initial 200 articles. Data analysis was conducted using a thematic descriptive approach to identify patterns in findings across three main themes: forms of digital PBL implementation, its effects on critical thinking and collaboration skills, and implementation challenges. The results of the study show that technologies such as Nearpod, Padlet, blended learning, mobile learning, and interactive media play an important role in enriching the PBL stages, while also improving critical thinking and collaboration skills by supporting information access and more dynamic learning interactions. However, implementing digital PBL faces obstacles, including limited facilities, teacher readiness, and variations in students' digital literacy. This study confirms that digital PBL has great potential to improve learning quality, with implications for facilities, teacher training, and the strengthening of digital competencies. Further studies are recommended to develop a more adaptive digital PBL integration model and media innovations that are appropriate for future learning needs.

Keywords: Blended Learning; Collaboration; Critical Thinking; Digital Learning; Problem-Based Learning.

Introduction

Science education plays a strategic role in equipping students with higher-order thinking skills to understand natural phenomena and solve complex environmental problems [1]. Bibliometric analysis of international publications shows that research on critical thinking skills in science education has increased significantly since 2015, with students as the dominant subject in these studies, indicating the importance of strengthening these skills in science education [2]. The findings also reveal that topics such as science education, environmental awareness, and systematic review form the main clusters in global research trends, showing that the development of critical thinking has become a central agenda in science education [3]. Furthermore, science learning that emphasizes the processes of analysis, evaluation, and scientific discussion has been reported to strengthen students' understanding of environmental issues and encourage environmental awareness [4], which ultimately requires the application of innovative, context-specific pedagogical approaches in science classrooms.

Problem-Based Learning (PBL) is a student-centered learning model through the process of authentic problem solving [5]. This approach encourages students to build deep understanding through investigation, discussion, and reflection on real problems [6]. PBL was also developed as a learning method that uses problems as a means to develop critical thinking and problem-solving skills [7]. In general, PBL places problems as the main driver of learning and makes students active participants in the process of knowledge construction. This approach encourages students to build deep understanding through investigation, discussion, and reflection on real problems as a means to develop critical thinking and problem-solving skills [8]. Overall, experts agree that PBL places problems as the main driver of learning and makes students active participants in the process of knowledge building [5]-[6]-[7].

Problem-based learning (PBL) is a learning model that encourages students to seek understanding independently by using real-world problems as the starting point for the learning process [9]. During this process, students naturally have to use their critical thinking skills, including evaluating information, analyzing data, making logical arguments, and drawing conclusions [10]-[11]. PBL is particularly relevant in science education because it encourages students to think critically: observing phenomena, formulating problems, searching for scientific concepts, testing arguments, and evaluating results [12]. With the development of digital technology, 21st-century learning requires integrating innovative pedagogical strategies with digital media [13]. Digital transformation in

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education, as stated by the, encourages learning innovations that are more adaptive, flexible, and oriented towards 21st-century skills [14]. The integration of technology is no longer just a complement but a necessity to create learning that is relevant to the characteristics of the digital generation, who are accustomed to quick access to information, interactive visualizations, and online collaboration. The use of digital platforms, interactive media, and online learning tools opens up opportunities to implement PBL in a more dynamic, contextual, and collaborative way [15]. With technological support, the processes of problem identification, information exploration, group discussion, and solution development can be carried out more effectively, enabling PBL to provide a richer learning experience aligned with the competency demands of the digital era [16].

However, not all digital learning implementations have been successful in improving students' critical thinking and collaboration skills. Research indicates that students may remain passive users if technology is not integrated with the appropriate pedagogical approach [17]. In addition, digital-based PBL faces challenges in the form of low digital literacy, gaps in teacher competence, and variations in the technological infrastructure available in schools [18]. These conditions indicate the need for learning strategies that combine the strengths of technology with the core characteristics of PBL to achieve learning objectives effectively.

The implementation of digital-based PBL still varies and has not been comprehensively documented in Indonesian or international educational contexts [19]. Some studies have developed digital tools, while others have used collaborative or blended learning platforms, but systematic mapping of the forms of implementation, their impact on critical thinking and collaboration skills, and the challenges of implementation remains limited. This gap highlights the need for research based on a Systematic Literature Review (SLR) to provide a structured, in-depth overview.

Based on the background description presented above, this study aims to explore the implementation of digital-based Problem-Based Learning (PBL) in the learning process, analyse its effect on the development of students' critical and collaborative thinking skills, and identify various obstacles and opportunities that arise in its application. In line with these objectives, this study focuses on three main questions, namely: (1) how digital-based PBL is implemented in the learning process, (2) how it impacts the improvement of students' critical thinking and collaboration skills, and (3) what are the challenges and opportunities that arise in its implementation.

Research Methods

This study uses the Systematic Literature Review (SLR) method, which is a structured and comprehensive approach to analyzing and interpreting scientific findings relevant to the research focus [20]. This method allows researchers to answer predetermined research questions through systematic analysis of available evidence [21]. The SLR approach distinguishes this review from traditional literature reviews, which tend to be narrative and subjective, while helping to identify patterns, trends, and differences in specific fields of study [22]. The article search was conducted using Publish or Perish version 8, with Google Scholar as the primary database. The search was conducted from October to December 2025 using a combination of the keywords “Problem-Based Learning,” “Digital Learning,” “Critical Thinking,” and “Collaboration.” The initial search stage yielded 200 articles that were potentially relevant for further analysis.

The articles obtained were then selected based on inclusion and exclusion criteria to ensure the quality and relevance of the sources. The inclusion criteria included publication between 2020 and 2025, discussion of digital-based PBL integration, measurement of critical thinking and/or collaboration skills, availability of full text, and status as a reliable scientific publication. Articles were excluded if they only discussed PBL without digital elements, only discussed digital learning without PBL, did not measure the main skills being studied, were not fully accessible, or were non-scientific publications. To maintain transparency and accuracy in the literature review process, this study adopted the PRISMA guidelines as a systematic article selection framework [23]. The framework comprises four main stages: identification, screening, eligibility, and inclusion. Each stage was carried out sequentially to replicate the selection process and improve the validity of the findings.

The article selection process followed the PRISMA 2020 flow. At the identification stage, 200 articles were collected through database searches using Publish or Perish. After eliminating duplicates and inaccessible articles, 160 articles remained for screening. At this stage, the titles and abstracts were evaluated, leading to the elimination of 85 articles that did not align with the study's focus. A total of 75 articles were then fully analyzed at the eligibility stage. Based on the inclusion criteria, 60 articles were excluded because they did not meet the requirements: PBL without digital elements (30 articles), digital learning without PBL (15 articles), did not measure key skills (10 articles), or were non-scientific publications or had inadequate methodology (5 articles). The final inclusion stage yielded 15 articles, which were used as the main sources for the systematic analysis.

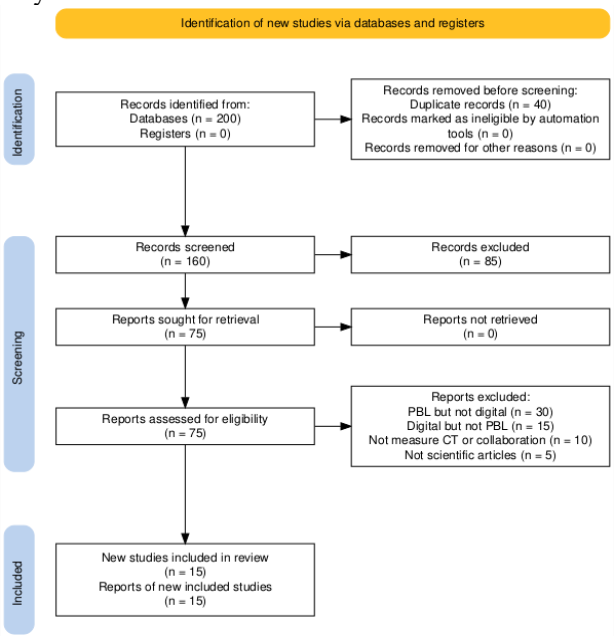

Figure 1. PRISMA chart of the selection process from 200 articles to 15 articles.

To ensure transparency and accuracy in conducting the literature review, this study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines as its framework. PRISMA is an international standard designed to improve the quality of reporting in systematic reviews by defining clear, structured selection criteria. This process involves four main stages: identification, in which all potential articles are collected from databases; screening, which involves removing duplicates and assessing relevance based on titles and abstracts; eligibility, which assesses the suitability of article content through full reading; and inclusion, which determines the final articles that meet all criteria. Through this framework, each selection step is systematic and replicable, thereby increasing the validity of the research findings. The application of PRISMA in this study is visualized through a flowchart (Figure 1), which illustrates the number of articles at each selection stage until a collection of relevant articles for analysis is obtained.

Results and Discussion

This study collected data from the analysis and synthesis of scientific articles discussing the application of digital problem-based learning (PBL) and its impact on students' collaboration and critical thinking skills. Identification, screening, eligibility, and inclusion followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which served as the basis for the article selection process. After these steps were completed, fifteen articles were identified for further analysis to evaluate the suitability of digital-based PBL for 21st-century learning objectives, particularly in improving students' critical thinking and collaboration skills. The findings were organized into three main themes: (1) the implementation of digital-based PBL models in learning contexts, (2) the impact of PBL on students' critical thinking and collaboration skills, and (3) emerging challenges and opportunities in PBL implementation.

Table 1. Review and Analysis of the Selected 15 Research Papers

Title	Journal	Research Result	Author
Pengembangan Perangkat Problem Based Learning untuk Meningkatkan Kemampuan Literasi Digital dan Berpikir Kritis Siswa Kelas V Sekolah Dasar	Journal of Education and Development Vol.8, No.4 (623-629)	The research results indicate that implementing the Problem-Based Learning (PBL) model significantly improves students' digital literacy. Specifically, post-test scores in digital literacy were higher than pre-test scores, with the average score increasing from 74 to 89 out of 100. The statistical analysis using a t-test shows a calculated t-value of 4.2, which is greater than the t-table value of 2.109, indicating a significant difference and suggesting that the PBL model effectively enhances digital literacy skills among students	[24]
Problem-Based Learning Assisted by the Padlet Application on Critical Thinking Abilities and Collaboration Skills	Journal of Education Action Research Vol.8, No.1 (177-126)	The research results indicated that the use of problem-based learning assisted by the Padlet application significantly improved students' critical thinking abilities and collaboration skills. Specifically, the experimental group, which used Padlet, showed a notable increase in both skills compared to the control group that used traditional learning methods. Statistical analysis using ANOVA confirmed that these differences were significant (p-value = 0.000), indicating that this instructional approach effectively enhances these competencies in students.	[25]
Penerapan Model Pembelajaran Problem Based Learning (PBL) dalam Blended Learning untuk Meningkatkan Kemampuan Kolaborasi, Keterampilan Berpikir Kritis, dan Penguasaan Konsep Matematika Kelas IV Sekolah Dasar XYZ Jakarta	Pendas: Jurnal Ilmiah Pendidikan Dasar Vol,7. No,2 (1119–1133)	The implementation of the Problem-Based Learning (PBL) model in blended learning improved students' collaboration and critical thinking skills, as well as their mastery of mathematical concepts. Students' average scores increased from pre-test to post-test across three cycles, with mastery of the mathematics concept reaching the minimum achievement standard (75) in the final cycle. Collaboration and critical thinking indicators also showed consistent improvement, as observed through questionnaires and assessment rubrics.	[26]
Pengembangan Media Pembelajaran Fisika Mobile Learning Berbasis STEM-PBL untuk Meningkatkan	Jurnal Lontar Physics Today Vol,4. No,2 (85-90)	The STEM-PBL-based mobile learning physics media was found to be highly feasible based on expert validation (85% material validity; 84% media validity). The product effectively	[27]

Keterampilan Berpikir Kritis dan Kolaborasi Siswa		improved students' critical thinking skills, shown by N-Gain scores of 0.44 (moderate) in the small-scale trial and up to 0.76 (high) in the large-scale trial. Students' collaboration skills also increased, with observation results in the "very good" category (88–97%), particularly in joint decision-making, task completion, respecting others' opinions, and idea sharing. These results indicate that the developed mobile learning media is effective in enhancing both critical thinking and collaborative skills in thermodynamics learning.	
Implementasi Media Interaktif Digital dalam Pembelajaran Problem Based Learning: Literature Review	JIIP (Jurnal Ilmiah Ilmu Pendidikan) Vol,8. No,8 (9964–9972)	Digital interactive media in PBL effectively improve motivation, engagement, understanding, and 21st-century skills, though infrastructure and teacher readiness remain challenges.	[28]
Peran Model Pembelajaran Problem- Base Lerning (PBL) Dalam Meningkatkan Kompetensi Peserta Didik Di Era Digital	Basilius Eirene: Jurnal Agama dan Pendidikan Vol,3. No,1 (42-57)	PBL effectively improves students' critical thinking, analytical, and independent skills. This approach also strengthens social skills, motivation, and a sense of responsibility in learning. Despite challenges such as time constraints and uncertainty, PBL is generally effective at improving students' competence in the digital age.	[29]
Penerapan Literasi Digital dalam Membangun Kemampuan Berpikir Kritis Siswa di Sekolah Dasar	Jurnal Ilmu Pendidikan Vol,8. No,2 (350-365)	Digital literacy implemented through various media and innovative learning approaches has proven effective in building critical thinking skills and character in elementary school students. These efforts demonstrate that integrating technology and digital literacy is an important strategy in 21st-century education that can significantly improve the quality of learning.	[30]
Peningkatan Keterampilan Kolaborasi dan Hasil Belajar Siswa Melalui Penerapan Model Problem Based Learning (PBL) Berbantu E-Modul	JGURUKU: Jurnal Penelitian Guru Vol,2. No,1 (632-639)	The implementation of Problem-Based Learning (PBL) assisted by e-modules successfully improved students' collaboration skills by 41.5% and learning outcomes by 68%. After the implementation, most students became more active in teamwork, and 86% of students achieved learning mastery	[31]
Peningkatan Kemampuan Literasi Digital Melalui Problem Based Learning dalam Pembelajaran IPS Kelas V di SDN Bulukerto 03 Batu	Jurnal Pendidikan Taman Widya Humaniora (JPTWH) Vol,2. No,3 (1348-1367)	The implemented learning model had a positive effect on students' learning outcomes and learning activities. After the learning intervention was applied, students demonstrated a better understanding of the material, increased participation during lessons, and higher achievement than in the initial condition. The improvement between the pre-test and post-test results indicates that the learning strategy used in this study was effective in enhancing student performance.	[32]
Pengaruh Modul Pembelajaran Problem Based Learning Berbantuan Media Komik Digital Terhadap Kemampuan Berpikir Kritis Siswa Pada Materi Fotosintesis Kelas IV SD Negeri	EDUKASIA: Jurnal Pendidikan dan Pembelajaran Vol,5. No,1 (841-850)	Implementation of Problem-Based Learning (PBL) assisted by digital comic media had a significant positive effect on students' critical thinking skills. Students' learning outcomes improved noticeably after the treatment, as shown by the increase in posttest scores compared to pretest scores. A paired-samples t-test yielded a p-value below 0.05, indicating that the improvement was statistically significant. These findings demonstrate that the PBL model supported by digital comic media is effective in	[33]

		enhancing students' critical thinking abilities in learning the photosynthesis material	
Pengaruh Pembelajaran Berbasis Masalah Dengan Media Digital Terhadap Kecakapan Berpikir Kritis Pada Pembelajaran Pendidikan Pancasila Kelas VIII MTsN 1 Trenggalek	Jurnal Pendidikan Pancasila dan Kewarganegaraan Vol,13. No,1 (49-61)	The implementation of Problem-Based Learning (PBL) assisted by digital media had a positive effect on students' critical thinking skills. Students taught using the PBL model demonstrated better learning outcomes than those taught through conventional methods. The improvement was seen in several aspects of critical thinking, including analysis, evaluation, and drawing conclusions. Statistical testing confirmed that the difference in results was significant, indicating that the PBL model supported by digital media is effective in improving students' critical thinking abilities.	[34]
Integrasi Manajemen Pendidikan, Deep Learning, dan AI dalam Pembelajaran Berbasis Masalah di SMK Kesehataan	AL-GAFARI Jurnal Manajemen dan Pendidikan Vol,3. No,2 (122-140)	The Problem-Based Learning (PBL) model had a positive and significant impact on students' learning outcomes. After implementing the PBL approach, students showed a better understanding of the learning material, as reflected in higher post-test scores than pre-test scores. The improvement demonstrates that students became more active, analytical, and engaged during the learning process. Statistical analysis confirmed that the increase in learning outcomes was significant, demonstrating that the PBL model effectively enhances students' academic performance.	[35]
Analisis penerapan dan pengembangan kurikulum merdeka belajar terhadap karakteristik 4c (communication, collaboration, critical thinking, and creativity) pembelajaran abad 21 tingkat sekolah menengah atas (sistematic literature review)	Jurnal Matematika dan Ilmu Pengetahuan Alam Vol,25. No,1 (38-43)	The implementation of the Merdeka Curriculum at the high school level has not been uniform, as most schools are still in the adaptation stage, though some have implemented project- and problem-based learning. This curriculum has a positive impact on communication, collaboration, and creativity through the use of digital media and group work, but developing critical thinking remains a challenge. Supporting factors include the use of technology and active learning methods, while inhibiting factors include limited ICT facilities, teacher readiness, and suboptimal authentic assessment, which require improved teacher training and support for digital infrastructure.	[36]
Integrasi Pembelajaran Kolaboratif untuk Penguatan Keterampilan Berpikir Kritis dalam Pendidikan IPA	MANDALA WIDYA: Jurnal Ilmu Pendidikan Vol,1. No,1 (13-25)	Digital-based learning models, particularly Project-Based Learning (PjBL) and Problem-Based Learning (PBL), positively influenced senior high school students' engagement, collaboration, and understanding of concepts through the integration of online platforms and digital media, although challenges remained in terms of infrastructure availability, teachers' digital competence, and the design of authentic assessments, indicating the need for stronger institutional support and professional development.	[37]

Enhancing Education Through Online Project-Based Learning (PBL): Strategies, Challenges, and Outcomes in the Digital Era	EDUCATIO: Journal of Education Vol,9. No,3 (265-277)	The study reports that the application of online and digitally supported Project-Based Learning contributed to higher student engagement, improved collaboration, and a better understanding of learning materials through the use of virtual platforms and multimedia resources. Nevertheless, its effectiveness was constrained by technical limitations, including unstable internet connections, unequal access to devices, and varying levels of digital competence among both teachers and students. The findings also emphasize that strong institutional support, continuous professional development, and adequate technological infrastructure are essential to maximize the benefits of digital-based PBL in contemporary classrooms.	[38]

Digital-Based PBL Implementation

The implementation of digital-based Problem-Based Learning (PBL) in various educational contexts shows a growing pattern from the use of digital learning tools to the use of more complex interactive media [39]. In general, integrating technology into PBL strengthens student-centered learning through investigation, collaboration, and problem-solving activities. This step is relevant to the demands of education in the digital age, where the ability to access information, think critically, and collaborate through digital platforms are important 21st-century skills [13]. In practice, Problem-Based Learning (PBL) is commonly implemented through several structured stages, including problem orientation, organizing learners for investigation, guiding individual and group inquiry, developing and presenting solutions, and analyzing/evaluating the problem-solving process [40]-[41]. When integrated with digital platforms, these stages can be facilitated through online discussion forums, collaborative documents, simulations, and multimedia resources, enabling students to engage in inquiry processes more systematically and flexibly.

The development of digital tools, such as modules and student worksheets, helps teachers implement PBL in a structured manner because they provide a systematic flow of activities in a digital learning environment [24]. This type of implementation serves as a foundation for more advanced technology integration. At the next level, utilized the Padlet platform to support PBL activities, especially in online discussions and brainstorming [25]. The use of Padlet made the problem exploration process more interactive and made it easier for students to express their opinions, so that collaboration could take place in real-time [42]. These findings are also consistent with research, which shows that the use of digital platforms such as Google Classroom and Moodle with real-time discussion features can optimize student interaction, collaboration, and critical reflection in online and blended learning [43].

The combination of online and face-to-face learning allows PBL activities to run more flexibly, while digital technology helps facilitate information gathering, group discussions, and solution presentations [26]. STEM PBL-based mobile learning media not only present content in digital format but also provide independent learning experiences through mobile applications that support problem analysis, concept exploration, and student reflection [27]. This expands the learning space so students can access PBL activities anytime, anywhere. These findings are also consistent with research showing that a combination of online and face-to-face learning supports collaboration, presentation, and space-time flexibility [44].

Interactive digital media, such as videos, animations, and simulations in PBL, showed that these technologies made problem-solving activities more interesting and easier to understand because students could visualize abstract concepts in a more concrete form [28]. PBL is considered capable of shaping 21st-century competencies, including technological literacy, collaboration, and higher-order thinking skills. This shows that digital integration is not just an addition but an important component of modern PBL [29]. This finding is in line with research, which reveals that digital media such as simulations, animations, and mobile learning applications can strengthen the investigation process, visualization of abstract concepts, and the development of 21st-century skills in a PBL environment [27].

Digital-based PBL also contributes to improving students' digital literacy. Through activities such as evaluating sources, searching for online information, and analyzing digital data, students not only solve problems but also develop the skills to select and validate credible information [30]. Thus, the application of PBL in a digital environment not only strengthens the learning process but also builds digital skills that are increasingly needed in the information age. This is consistent with research, which shows that the application of PBL in a digital environment can directly improve students' digital literacy through information search activities, source evaluation, and the use of technology in problem solving [45].

Overall, these seven studies show that the application of digital-based PBL spans a broad spectrum, from device development and the use of collaborative platforms to blended models, mobile learning, and the strengthening of digital literacy. Despite their differences, all of these implementations show the same pattern: digital technology enriches the PBL stages (problem orientation, exploration, discussion, and reflection), increases student participation, and creates a more dynamic, context-rich learning experience. This integration is in line with the theory which emphasizes that PBL is effective when students actively

interact with authentic problems through an investigative process [5], as well as which states that PBL requires a learning environment that supports collaboration and reflection, two aspects that are actually strengthened by digital technology [6].

The Impact of PBL on Critical Thinking and Collaboration Skills

The impact of consistently implementing digital-based Problem-Based Learning (PBL) shows an increase in students' critical thinking and collaboration skills at various levels of education. Strengthening these two competencies is relevant because they are core components of the 21st-century skills needed in today's digital society [16]. Through the PBL approach, students are not only involved in the problem-solving process, but also actively interact in a digital environment that supports collaborative work, information exploration, and group communication [1].

PBL assisted by e-modules has a significant impact on the development of student collaboration [31]. Digital e-modules allow students to access PBL steps independently, while problem-solving activities are still carried out in groups. With a structured task design, students practice dividing roles, providing input, and solving problems together. This is evident in a 41.5% increase in collaboration, indicating that the use of digital media can strengthen group cooperation. These findings are consistent with studies on PBL based e-module development that report improvements in collaboration skills and learning effectiveness through the use of structured e-modules [46].

The application of PBL in social studies learning to improve students' digital literacy. Although the main focus of this study is digital literacy, the activities carried out in PBL require students to critically select, analyze, and compare information [32]. The results show that digital literacy increased from low to moderate (43.75% → 69%), indicating an increase in critical thinking skills. PBL facilitates students to identify relevant information and make decisions based on available data, two core aspects of critical thinking. These findings are in line with a study by, which shows that increased digital literacy through PBL activities directly contributes to strengthening critical thinking skills, especially in the process of analyzing, evaluating, and validating digital information [47].

Comic media, which presents problems in visual and narrative form, makes it easier for students to understand the context of the problem before trying to find a solution [33]. The study found a significant increase in critical thinking scores, from an average of 42 on the pretest to 73 on the posttest. These findings show that engaging with digital media can strengthen students' motivation and analytical skills, thereby making the PBL process more effective. Digital visualization helps students understand problems more deeply, then develop the skills to analyze, evaluate, and conclude information [48]. This finding is reinforced by a study which shows that the integration of digital media in PBL models consistently improves critical thinking skills through case analysis, data-based argumentation, and interactive discussion processes [49].

Digital media makes it easier for students to explore case studies, discuss solutions, and build arguments based on evidence [34]. The results of the study show a significant difference between the experimental and control classes, with the digital PBL class achieving higher critical thinking scores. The interactive process of problem exploration provides students with opportunities to practice reasoning, express opinions, and defend arguments logically. This finding is in line with research, which shows that the integration of multimedia such as animation and simulation in PBL models can improve critical thinking skills through concept exploration and evidence-based discussion [50].

Digital media, such as simulations and animations, help students understand biological phenomena more concretely, so that the process of problem identification and solution analysis can be carried out more deeply [35]. Statistical test results show that both critical thinking skills and learning outcomes increased significantly in the experimental class compared to the control class. The group discussion process in a digital environment enabled students to exchange ideas more structured and test their understanding of the concepts being studied. These findings are consistent with previous studies reporting that the integration of PhET simulations and animated videos in science learning significantly improves students' critical thinking skills and conceptual understanding compared to conventional instruction, thereby strengthening the effectiveness of digital-based learning environments [51].

Overall, the five studies show a consistent pattern: integrating digital technology into PBL enriches the learning experience and strengthens its core phases, including problem identification, information gathering, analysis, collaboration, and reflection. Digitization makes the investigation process more accessible and interactive, giving students more space to explore ideas and engage in productive collaboration. This is in line with the opinion of, who emphasizes that PBL helps students build deep understanding through the investigation process [5], as well as those who state that analysis, evaluation, and creation activities are key indicators of high-level critical thinking [17]. Thus, the use of digital technology is not only a tool but also plays a role in significantly strengthening the effectiveness of PBL in developing critical thinking and collaboration skills.

Challenges and Opportunities in Implementing Digital-Based PBL

The implementation of digital-based Problem-Based Learning (PBL) not only has a positive impact on the learning process but also presents several challenges that need to be considered. Although digital technology can enrich investigation and collaboration activities in PBL, the success of this model depends heavily on the readiness of infrastructure, teacher capabilities, and student digital literacy [52]. In this context, the studies analyzed show that the implementation of digital PBL moves in a complex dynamic between obstacles and opportunities that open up space for educational innovation.

The implementation of Merdeka Curriculum-based learning, including digital PBL, is still gradual and uneven across schools [36]. Factors such as limited technological infrastructure, internet access, and the readiness of digital learning devices hinder the optimal implementation of PBL [15]. In addition, improving critical thinking skills requires specific strategies, and the use of digital technology has not fully overcome these obstacles. These obstacles show that

integrating technology into PBL requires support from school policy, improved facilities, and adequate training for effective implementation. Similarly, research found that internet connectivity and infrastructure problems in rural areas significantly hamper the effectiveness of online blended learning, showing that the success of digital PBL is highly dependent on infrastructure conditions and equitable access [53].

Pedagogical challenges, namely, how teachers create digital collaborative spaces that facilitate meaningful interactions [37]. Digital collaborative learning requires careful planning to enable students to actively engage in discussions, exchange ideas, and solve problems. Teachers' skills in managing group activities on digital platforms are an important factor [54]. If teachers lack adequate digital competence or are unfamiliar with online facilitation models, the PBL process may be less effective. However, this study also emphasizes the great opportunity that digital social interaction, if managed properly, can create a strong collaborative environment and significantly support the development of critical thinking. These findings are in line with research, which shows that the success of digital collaboration in PBL is greatly influenced by teachers' pedagogical competence and digital literacy, particularly in designing group activities and facilitating meaningful online interactions [55].

The implementation of Online Project-Based Learning supported by digital media has been shown to enhance student engagement, critical thinking skills, collaboration, and technological literacy. However, several constraints remain, including limited access to devices and stable internet connections, reduced face-to-face interaction, difficulties in assessing individual contributions in group work, and insufficient teacher preparedness in utilizing digital platforms [38]. Nevertheless, when adequate infrastructure, teacher training, and students' digital competencies are strengthened, digital-based PBL can create more contextual, engaging, and effective learning experiences. These findings are consistent with previous research indicating that low digital literacy and unequal access to technology continue to be major challenges in digital learning environments, although significant opportunities emerge when infrastructure and technological understanding are improved [56].

Overall, the findings on this theme illustrate that the challenges of implementing digital-based PBL can be categorized into three main aspects: (1) limitations in digital infrastructure and facilities; (2) teachers' readiness and competence in managing technology-based learning; and (3) variations in students' digital literacy. However, alongside these challenges, there are also great opportunities for developing learning innovations. Digital technology can increase learning flexibility, support collaborative work across space and time, and enrich the inquiry process in PBL by presenting more visual and interactive information.

This pattern of findings is consistent with the view that the effectiveness of PBL is strongly influenced by the quality of the learning environment and the way digital systems are managed, where technology functions not merely as an additional tool but as a catalyst for enhancing learning quality [6]. Similarly, PBL is argued to require a support system that enables inquiry, collaboration, and reflection in learning processes [5]. Thus, despite substantial challenges, infrastructure development, improvement of teacher competence, and strengthening of students' digital literacy represent strategic opportunities for optimizing the future implementation of digital-based PBL.

Conclusion

Based on a systematic review of 15 selected studies, it can be inferred that integrating Problem-Based Learning (PBL) with digital learning consistently enhances the overall quality of the learning process by fostering a more interactive, flexible, and learner-centred instructional environment. Various forms of application were found, ranging from digital learning tools and Padlet to blended and mobile learning, as well as interactive media, showing that technology plays an important role in enriching the core stages of PBL, such as problem orientation, exploration, discussion, and reflection. This integration has been proven to improve students' critical thinking and collaboration skills because technology facilitates access to information, promotes the exchange of ideas, and enables more in-depth investigation of problems. However, the implementation of digital PBL still faces challenges, including infrastructure limitations, teacher readiness, and variations in student digital literacy, indicating the need for facility support, training, and strengthening digital competencies for optimal implementation. Thus, this study confirms that digital-based PBL has great potential to improve the quality of learning in the technological era, and further studies can focus on developing more adaptive integration models, strengthening teacher capacity, and innovating digital media that are more responsive to 21st-century learning needs.

Author's Contribution

A. Mardiyah conceptualized the study, formulated the research questions, conducted the literature search, performed data synthesis, and drafted the manuscript. S. Wahyuni contributed to article screening and data extraction. S.S.A.Q. Barid: assisted with thematic analysis and manuscript revision. S.R.D. Astuti: as the corresponding author, supervised the research process, provided academic guidance, and approved the final version of the manuscript. All authors read and agreed to the published version of the manuscript

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