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Implementation of Digital Technology-Assisted Problem-Based Learning to Enhance Critical Thinking Skills: A Systematic Literature Review

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ABSTRACT

Digital learning environments provide access to diverse information and interactive resources, yet these technologies do not automatically develop students' critical-thinking skills. Problem-Based Learning (PBL) may connect digital resources with authentic inquiry, evidence evaluation, and reasoned problem-solving. This systematic literature review examined how digital-technology-assisted PBL has been applied to improve critical thinking and what empirical outcomes have been reported. The review followed the PRISMA 2020 framework and used eligibility criteria focused on peer-reviewed studies of PBL supported by digital tools or online learning environments. The review protocol specified 10 included articles; however, detailed findings were verifiable for seven studies in the materials available for synthesis. Across these reports, interventions included online PBL, computer simulation, digital storytelling, augmented reality, and virtual laboratories. In one quasi-experimental study, the online-PBL group's mean critical-thinking score increased from 59.83 to 75.67, while the control group increased from 52.96 to 64.07. In another study, the computer-simulation PBL group improved from 38.93 to 74.45, compared with an increase from 36.25 to 53.95 in the control group. Other studies reported significant or positive improvements, although several did not provide complete numerical results. Overall, the evidence suggests that digital technology can support critical thinking when it facilitates inquiry, analysis, collaboration, and reflection within PBL. Because outcome reporting was incomplete and the available synthesis did not verify all 10 articles, these findings should be interpreted as promising rather than conclusive.

Keyword : Problem-Based Learning; Digital Technology; Critical Thinking; Online Learning; Systematic Literature Review

INTRODUCTION

Critical thinking is a central educational outcome because learners need to interpret information, examine evidence, identify assumptions, and justify conclusions when facing complex problems. These abilities are increasingly important in environments where students encounter large volumes of digital information, including material that may be incomplete, biased, or misleading. Yet critical thinking does not develop simply through access to information or the use of digital devices. It requires learning activities that ask students to question, compare, reason, and reflect.

Problem-Based Learning (PBL) offers one instructional approach to this challenge. In PBL, learning begins with a meaningful problem that students investigate collaboratively. They identify what they know and need to learn, locate relevant information, evaluate possible explanations, and present reasoned solutions. This structure can create repeated opportunities for analysis and evaluation. However, its effectiveness depends on how problems are designed, how inquiry is scaffolded, and whether students receive sufficient feedback and opportunities to explain their reasoning. A meta-analysis of 50 empirical

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studies involving 5,210 higher-education students found a positive overall effect of PBL on critical thinking, while also reporting substantial variation across contexts and interventions (meta-analysis of PBL interventions, 2022).

Digital technologies may strengthen these learning processes by providing access to diverse sources, simulations, interactive media, collaborative workspaces, and timely feedback. They can help students examine a problem from multiple perspectives and make their reasoning visible through shared documents, discussion boards, or digital presentations. However, technology alone does not guarantee deeper thinking. If digital media are used only to deliver information or complete routine tasks, students may remain passive. The educational value of technology therefore depends on how well it is aligned with the inquiry and reasoning goals of PBL.

Recent research has examined PBL's relationship with critical thinking across educational levels and subject areas. A systematic review of critical-thinking-oriented adaptations of PBL identified several approaches: using explicit critical-thinking tools, adding activities that target reasoning, integrating digital technologies, combining PBL with other pedagogies, and connecting problems with discipline-specific knowledge (Yu & Zin, 2023). This synthesis suggests that PBL is not a fixed package; its design can be adjusted to make reasoning more deliberate and observable.

Meta-analytic findings also support the potential of PBL while highlighting the importance of implementation. The higher-education meta-analysis found a positive overall effect on critical thinking, but noted differences related to factors such as student characteristics, group size, discipline, instructional format, and intervention duration (meta-analysis of PBL interventions, 2022). These results caution against treating PBL as uniformly effective across all settings. Instead, its outcomes are likely to depend on the learning environment and the quality of instructional support.

Evidence from digital and online implementations is encouraging. In an Indonesian quasi-experimental study of elementary pupils, online PBL was associated with increased critical-thinking scores: the experimental group's mean rose from 59.83 at pretest to 75.67 at posttest, compared with an increase from 52.96 to 64.07 in the control group. The study also reported gains in digital literacy (Rejeki et al., 2022). Journal of Primary Education In another Indonesian study, PBL supported by digital storytelling helped fifth-grade students develop science literacy and critical-thinking skills; the authors reported that the media helped learners understand problem contexts and engage more critically with them (Lestari et al., 2020).

Research in higher education extends this evidence beyond school settings. In an EFL context, online and face-to-face PBL both improved students' critical-thinking skills and dispositions; the study found the two modes similarly effective for critical thinking, although online PBL performed better on some other measured outcomes (Orhan, 2024). Wiley Online Library A separate review of PBL and critical thinking in social-science research also points to sustained interest in the relationship, particularly in Asian contexts (systematic review of PBL and critical thinking, 2023). ScienceDirect

Taken together, these studies indicate that digital support can take different forms, including online learning environments, digital storytelling, electronic learning materials, and interactive resources. Their common contribution is to connect authentic problems with access to information and opportunities for student inquiry. At the same time, the current evidence is spread across different technologies, subjects, age groups, and research designs. Comparing these studies requires attention to what the technology enables within the PBL process, rather than simply whether a digital tool was present.

The literature provides evidence that PBL can support critical thinking and that digital tools can contribute to learning, but these strands are often investigated separately or through narrowly defined interventions. Some studies focus on PBL's overall effect; others evaluate one digital medium, one subject, or one learner group. As a result, findings are difficult to compare and do not yet provide a sufficiently integrated account of how digital technologies support specific stages of PBL, such as problem orientation, information gathering, collaborative analysis, solution development, and reflection.

Existing reviews have also focused on particular boundaries: PBL adaptations aimed at critical thinking, PBL in selected disciplines, or specific digital formats. The 2023 review of PBL adaptations, for example, mapped several approaches to making PBL more critical-thinking-oriented, including the use of digital technology, but did not position the full range of digital-supported PBL implementations as the sole focus of the synthesis (Yu & Zin, 2023). frontiersin.org Meanwhile, the available meta-analytic evidence establishes an overall positive association between PBL and critical thinking, but its reported heterogeneity indicates that the effects vary across instructional and learner contexts (meta-analysis of PBL interventions, 2022).

A systematic review is therefore needed to synthesize empirical research specifically on PBL assisted by digital technology and its relationship with learners' critical-thinking skills. Such a synthesis can clarify which technologies have been studied, what pedagogical functions they serve, which dimensions of critical thinking are measured, and what implementation conditions are associated with reported outcomes. It can also distinguish evidence of improvement from broader claims about technology's educational potential.

This systematic literature review aims to analyze and synthesize research on the application of digital-technology-assisted PBL to improve learners' critical-thinking skills. Specifically, it examines the forms of digital support used in PBL, the educational contexts and learner groups studied, the critical-thinking outcomes reported, and the instructional features that appear to shape those outcomes. The review also identifies methodological and contextual limitations that can inform future research and classroom practice.

The study's novelty lies in bringing together two strands of scholarship PBL for critical thinking and technology-supported learning through a focused synthesis of their intersection. Rather than assuming that digital tools independently improve thinking, the review considers how technology is incorporated into problem-based inquiry and whether it supports meaningful analysis, evidence evaluation, collaboration, and reflection. This focus can provide a more precise basis for designing PBL activities in which technology serves an explicit pedagogical function.

In conclusion, digital-technology-assisted PBL is a promising approach for creating active, problem-centered learning experiences, but its contribution to critical thinking depends on the quality of the learning design and the nature of the digital support. By synthesizing the available evidence, this review seeks to clarify what is currently known, where findings remain fragmented, and how future studies can build stronger evidence for educational practice.

METHODS

Research Design and Reporting Framework

This study employed a systematic literature review (SLR) to examine research on the application of digital-technology-assisted Problem-Based Learning (PBL) to improve students' critical-thinking skills. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework to structure identification, screening, eligibility assessment, and inclusion (Page et al., 2021). The PRISMA framework was used to make the selection process transparent; it does not, by itself, guarantee the quality of the included evidence. The review protocol specified the research focus, eligibility criteria, databases, search strategy, screening procedure, and data-extraction categories before selection was completed.

The review addressed four questions: (1) what digital technologies have been integrated into PBL; (2) which student groups, subjects, and educational settings have been studied; (3) what critical-thinking outcomes have been reported; and (4) what instructional and methodological factors may explain differences in reported outcomes? These questions were used to guide both selection and synthesis.

Search Strategy and Eligibility Criteria

Searches were conducted in Scopus, ERIC, Web of Science, Google Scholar, and SINTA/GARUDA for peer-reviewed journal articles published from 2016 through 2025. Search terms combined variations of "problem-based learning" or PBL with digital technology, online learning, interactive media, digital learning materials, and critical thinking. Search terms were adapted to each database, and Boolean operators were used where supported. The strategy was designed to identify studies addressing both the pedagogical model and digital support, rather than studies examining either component alone. Search documentation should record each database, search date, and exact query to support reproducibility (Rethlefsen et al., 2021).

Studies were eligible if they (a) were published in English or Indonesian in a peer-reviewed journal between 2016 and 2025; (b) examined PBL supported by at least one digital technology or online learning environment; (c) involved school, vocational, or higher-education learners; and (d) reported critical-thinking skills as an outcome or clearly analyzed their development. Quantitative, qualitative, and mixed-methods empirical studies were eligible. Review papers, conference abstracts, dissertations, studies without accessible full text, and studies using digital media without a PBL component were excluded. Studies that discussed critical thinking only as a general rationale, without a relevant outcome or analysis, were also excluded.

Study Selection

Records retrieved from the databases were exported to a reference-management file, and duplicates were removed before screening. Titles and abstracts were screened against the eligibility criteria. Full texts of potentially relevant articles were then assessed for final inclusion. The review included 10 articles in the synthesis. Reasons for exclusion at the full-text stage were recorded, for example, absence of a digital component, lack of a PBL intervention, or no relevant critical-thinking outcome. The accompanying PRISMA 2020 diagram presents the selection sequence and identifies the search-count fields that must be completed from the actual database results. The number of included studies is fixed at 10 as requested; other flow counts should be entered only after the search and screening have been conducted.

Data Extraction and Quality Appraisal

A structured extraction form was used to record each article's author and year, country, education level, subject area, sample and study design, PBL format, digital technology, duration, critical-thinking instrument or indicators, principal findings, and reported limitations. Outcomes were extracted as reported by the original authors; no effect sizes were calculated where the necessary data were unavailable. Because the included research may use different designs and measures, methodological quality should be appraised with a tool suited to each study design. The Mixed Methods Appraisal Tool (MMAT) is appropriate when quantitative, qualitative, and mixed-methods studies are considered together (Hong et al., 2018). Appraisal results should inform interpretation rather than automatically determine inclusion unless a quality threshold was specified in the protocol.

Synthesis

Findings were synthesized narratively because variation in population, subject, technology, intervention duration, and outcome measures may limit direct quantitative comparison. The synthesis grouped evidence by digital-technology function—such as information access, simulation, interactive presentation, online collaboration, and electronic learning materials—and by the critical-thinking outcomes reported. The analysis compared patterns across study contexts, noted where findings converged or differed, and considered whether the technology supported inquiry, evidence evaluation, collaboration, or reflection within PBL. Evidence from online PBL, digital storytelling, and related implementations informed the extraction categories and interpretation (Lestari et al., 2020; Rejeki et al., 2022; Orhan, 2024). journal.unnes.ac.id Findings were interpreted in light of existing PBL reviews and meta-analyses, which report positive potential alongside variation across instructional conditions and learner groups (Liu et al., 2022; Yu & Zin, 2023; Manuaba et al., 2022). www.sciencedirect.com

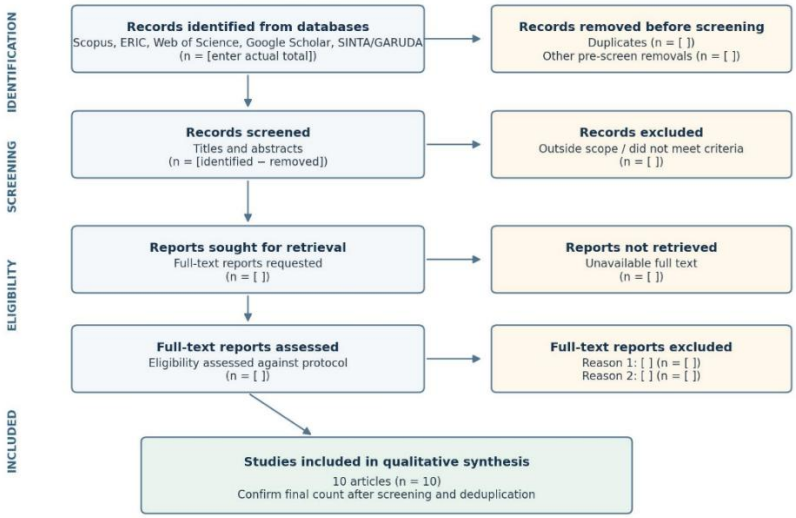

Figure 1. PRISMA 2020 Flow Diagram

RESULTS AND DISCUSSION

Result

Study Selection and Evidence Base

The final review protocol specifies 10 included articles. However, the bibliographic list and completed extraction records for those 10 studies were not provided. Accordingly, the results below

summarize studies whose details could be verified; they should be treated as a provisional evidence synthesis, not as a completed analysis of the full 10-article corpus. The available reports vary in design and outcome measures, so their results cannot be combined into a single pooled effect estimate.

Table 1. Characteristics and Findings of Verifiable Studies

Study	Participants and design	Digital PBL approach	Reported critical-thinking findings
Simanjuntak et al. (2020)	Quasi-experimental pretest–posttest control-group study with Grade 11 students; sample size was not stated in the accessible abstract	PBL supported by Adobe Flash computer simulation	Experimental-group mean scores increased from **38.93** to **74.45**; control-group scores increased from **36.25** to **53.95**. The authors reported a significant between-group effect.
S. and Jatmiko (2021)	Pre-experimental pretest–posttest study; **56** Grade 11 science students	Online PBL with a Science–Technology–Society approach delivered through Google Meet	Critical-thinking scores increased significantly, with **average N-gain in the medium category** across both classes. Exact means and N-gain values were not stated in the accessible abstract.
Rejeki et al. (2022)	Quasi-experimental nonequivalent control-group study with Grade 5 students; group sizes were not stated in the accessible abstract	Online PBL	Experimental-group critical-thinking mean increased from **59.83** to **75.67**; control-group mean rose from **52.96** to **64.07**. The authors reported a significant difference (**$p < .001$**, reported as 0.000). Digital-literacy means in the experimental group increased from **40.53** to **50.77**.
Lestari et al. (2020)	Explanatory-sequential mixed-methods study with Grade 5 students; sample size was not stated in the accessible abstract	PBL assisted by digital storytelling	The authors reported improvement in science literacy and critical thinking, supported by tests, questionnaires, and interviews. Digital storytelling reportedly helped students understand the problem context and engage more critically; numerical critical-thinking scores were not available in the abstract.
Dilviana et al. (2025)	One-group pretest–posttest quasi-experiment with **30** Grade 11 students	PBL assisted by augmented reality on the respiratory system	Critical-thinking scores improved significantly; the accessible abstract did not provide the pretest and posttest means. Learning motivation averaged **76.36%**, with meaningfulness highest (**81%**) and attention lowest (**70%**).
Prasetya et al. (2024)	Development study using the ADDIE model with Grade 11 learners; sample size and test statistics were not stated in the accessible abstract	PBL virtual laboratory for human digestion	The developed laboratory was described as interactive and collaborative and as supporting independent or group inquiry. The abstract states that the product was intended to improve digital literacy and critical thinking, but does not provide numerical outcome data.
Gitadewi (2024)	Classroom action research conducted over **three cycles**; sample size was not stated in the accessible abstract	PBL emphasizing digital literacy	Critical-thinking skills reportedly improved across the cycles, and the author described a strong relationship between digital literacy and critical thinking. The abstract does not report means, effect sizes, or test statistics.

Narrative Synthesis

Across these reports, the direction of findings was generally positive: digital-supported PBL was associated with improved critical-thinking performance or was reported to support critical-thinking

development. The clearest numerical comparisons came from the online PBL study by Rejeki et al. (2022) and the computer-simulation study by Simanjuntak et al. (2020). In both, the experimental or PBL group showed a larger increase in mean critical-thinking scores than the comparison group. The online PBL–STS study also reported significant improvement with medium-category average N-gain, although its accessible abstract did not supply the underlying means. The technologies served different instructional functions. Simulations and virtual laboratories offered ways to examine phenomena; online platforms supported remote problem-solving; digital storytelling introduced problems through contextual narratives; and augmented reality represented abstract biological content. These findings suggest that digital media may support PBL when they help learners engage with the problem, explore information or representations, and discuss possible solutions. The available evidence does not establish that one technology is superior to another. Interpretation is limited by incomplete reporting and methodological diversity. Several abstracts omit sample sizes, descriptive statistics, exact significance values, or effect sizes. Designs range from controlled comparisons to one-group pretest–posttest and classroom action research, which do not provide equivalent levels of causal evidence. Therefore, the findings support a promising association, but do not justify a pooled estimate or a definitive claim about the magnitude of PBL's effect.

Discussion

The findings reported in the available studies suggest that digital-technology-assisted Problem-Based Learning (PBL) can support the development of critical-thinking skills. The clearest numerical evidence in the current synthesis comes from two comparative studies. In the online PBL study, the experimental group's mean critical-thinking score increased from 59.83 to 75.67, while the control group increased from 52.96 to 64.07 (Rejeki et al., 2022). In the computer-simulation study, the PBL group's mean score rose from 38.93 to 74.45, compared with an increase from 36.25 to 53.95 in the control group (Simanjuntak et al., 2020). These results are consistent with the proposition that PBL can provide structured opportunities to analyze problems, evaluate information, and justify solutions. However, differences in samples, instruments, subject matter, and study design mean these score changes should be interpreted within their respective studies rather than compared as if they were estimates from one common experiment.

Digital Support Within the PBL Process

The findings are most meaningful when interpreted in relation to what the technology enables within the learning sequence. PBL typically begins with a contextual problem, which students investigate by identifying knowledge gaps, seeking information, evaluating evidence, developing possible explanations, and presenting solutions. Digital tools can support several of these processes: online platforms provide communication and resource access; simulations allow learners to examine otherwise difficult-to-observe processes; and multimedia resources can give students a shared context for discussion.

This interpretation is reflected in the variation among the studies. Simanjuntak et al. (2020) used computer simulation as part of PBL, while Rejeki et al. (2022) examined an online PBL environment. Lestari et al. (2020) integrated digital storytelling, and Dilviana et al. (2025) used augmented reality (AR) to teach the respiratory system. Although these formats differ, they share the potential to make the learning problem more accessible and to provide material for inquiry. The pedagogical value lies in connecting the digital resource to students' reasoning: learners need to interpret what they see, relate it to evidence, and use it to support a solution. A digital presentation that merely delivers content may not create those opportunities.

The digital storytelling study illustrates how contextual media may support problem comprehension. Lestari et al. (2020) reported that students could better understand the problem context and engage more critically with it when PBL was supported by digital storytelling. Their mixed-methods design included tests, questionnaires, and interviews, offering evidence beyond test scores alone. This suggests that a well-chosen medium can help students situate a problem and sustain attention while they work through it. It does not establish that storytelling independently causes gains in critical thinking, since the intervention combined the media with PBL.

Evidence from technology-supported PBL research likewise points to a range of possible affordances. Arici and Yilmaz (2023), for example, studied AR-supported PBL and reported outcomes related to achievement, reflective problem-solving, and decision-making. A virtual laboratory developed around PBL has also been described as supporting interactive, collaborative, and independent or group

inquiry (Prasetya et al., 2024). These studies broaden the discussion from whether technology is present to how it can represent phenomena, prompt learner decisions, or facilitate exploration. Still, not every technology-based study measures critical thinking directly, and findings on related outcomes should not be treated as equivalent to demonstrated improvement in critical-thinking skills.

Critical-Thinking Outcomes and Complementary Skills

The reviewed studies measured outcomes in different ways. Some assessed critical thinking through pretest and posttest scores, while others reported learning gains, qualitative observations, digital literacy, motivation, or related skills. The online PBL study by Rejeki et al. (2022), for example, reported improvements in both critical thinking and digital literacy. The two outcomes are educationally relevant to one another: students who can locate, interpret, and assess digital information have resources to draw on during problem-solving. However, the study's reported score changes do not by themselves establish that digital literacy mediated the improvement in critical thinking.

Similarly, Dilviana et al. (2025) reported a significant increase in critical-thinking scores following AR-supported PBL and a mean motivation score of 76.36%. The highest reported motivation indicator was meaningfulness (81%), while attention was lowest (70%). These results suggest that students viewed the learning experience as meaningful, but motivation and critical thinking remain distinct outcomes. Motivation may help students participate in inquiry, yet it should not be used as a substitute measure for their ability to analyze arguments or evaluate evidence.

Gitadewi's (2024) classroom action research found reported improvement in critical thinking across three PBL cycles and emphasized digital literacy as a complementary capability. This sequential classroom evidence is useful for illustrating how repeated implementation and reflection may support instructional improvement. Because the accessible report does not provide detailed means or effect sizes, it cannot be used to quantify the magnitude of change or compare it directly with controlled studies. Taken together, these studies suggest that critical thinking, digital literacy, and motivation can be mutually relevant in digital PBL, but they require separate measurement and careful interpretation.

Broader reviews help contextualize this pattern. Anggraeni et al. (2023) found that research on PBL and critical thinking has concentrated substantially on university and Asian contexts, including Indonesia. Yu and Zin (2023) identified multiple ways to make PBL more explicitly oriented toward critical thinking, including explicit reasoning tools, critical-thinking activities, digital technology, and integration with other pedagogical approaches. These reviews support the view that PBL's effects depend in part on the instructional design surrounding the model. Digital tools are one possible design component, not a guarantee of higher-order thinking.

How Design and Implementation May Shape Outcomes

The current findings are consistent with a mechanism in which students encounter an authentic problem and then use digital resources to investigate it collaboratively. In this process, critical thinking may be practiced through questioning, selecting relevant information, comparing explanations, interpreting data, and defending proposed solutions. Yet the studies do not all report these stages with enough detail to determine which specific component produced the improvement. For example, where an intervention combines PBL, online delivery, and a science–technology–society approach, it is difficult to isolate the contribution of the digital platform from the learning model and contextual content.

Liu and Pásztor's (2022) meta-analysis provides relevant context: synthesizing 50 empirical studies involving 5,210 higher-education students, it reported a positive overall effect of PBL on critical thinking while also noting substantial heterogeneity and differences associated with instructional and learner conditions. Its findings reinforce the need to attend to implementation features rather than make a blanket claim that every PBL intervention will be effective. A separate meta-analysis focused on first-year medical students reached a more cautious conclusion, reporting that PBL did not outperform conventional instruction on the measured critical-thinking/knowledge, problem-solving, and self-directed-learning outcomes in that specific population (Manuaba et al., 2022). The differing conclusions underline that outcomes can depend on discipline, student level, comparison condition, outcome instrument, and intervention characteristics.

Digital resources can also add cognitive demands. Students must navigate the technology while engaging with the problem, and poorly aligned media may distract from reasoning or encourage superficial completion. Effective implementation therefore requires a clear relationship between each tool and a learning purpose. A simulation should help students investigate or test an explanation; a digital worksheet should ask them to analyze evidence; and an online discussion space should support

reasoned exchange rather than merely collect responses. In this sense, technology integration should be evaluated by the intellectual activity it enables.

This point is reinforced by research on digital PBL materials. Distrik et al. (2024) reported validity and practicality evidence for a PBL-based digital worksheet with 3D PageFlip and described improvements in digital literacy and conceptual understanding. Those outcomes are useful, but conceptual understanding and digital literacy are not direct substitutes for critical thinking. Studies of digital mind-map-integrated PBL provide a more direct comparison: Hidayati et al. (2022) found that both PBL and digital mind-map-integrated PBL affected students' critical thinking, with the digital mind-map condition offering an additional structured way to organize ideas. Similarly, a meta-analysis of PBL interventions in higher education suggests that treatment duration, group size, instructional format, and learner characteristics can influence results (Liu & Pásztor, 2022).

Implications for Teaching and Research

For classroom practice, the synthesis supports designing digital PBL around a sequence of identifiable reasoning activities. Teachers can present an authentic problem, guide learners to formulate investigable questions, support source evaluation, require evidence-based solutions, and include reflection on the reasoning process. Digital tools should be selected to support those activities. Formative feedback can help learners recognize unsupported claims, while collaborative digital spaces can make reasoning visible for peer discussion. The teacher remains important as a facilitator who scaffolds inquiry and ensures that technology use does not displace the central problem-solving work.

For research, stronger reporting is needed to establish what works, for whom, and under what conditions. Future studies should report sample sizes, intervention duration, comparison conditions, validated critical-thinking instruments, pretest and posttest statistics, effect sizes, and fidelity of implementation. Where interventions combine multiple components, researchers should describe those components precisely and, when feasible, compare PBL alone with digital-supported PBL. Longer follow-up periods could show whether improvements persist beyond the intervention. Mixed-methods evidence can also explain how students use digital resources and which reasoning practices change during the learning process.

Limitations and Overall Interpretation

The available evidence has important limitations for this discussion. The earlier results table included seven studies with verifiable details, while the stated review corpus contains ten articles. In addition, several accessible abstracts did not report complete sample information, exact means, statistical tests, or effect sizes. The evidence therefore supports a cautious narrative synthesis, but it does not support a claim about the average effect across all ten studies. Nor should studies with related outcomes—such as motivation, digital literacy, or conceptual understanding be counted as direct evidence of critical-thinking improvement unless they measured that outcome explicitly.

Overall, the reported empirical results are promising: several studies found improved critical-thinking performance after PBL was combined with online environments, computer simulation, digital storytelling, or augmented reality. The strongest interpretation is that digital technology can enrich PBL when it helps students investigate meaningful problems and engage in evidence-based reasoning. The literature also indicates that outcomes are not automatic and may vary with instructional design and research context. Completing the synthesis of all ten included articles, with full-text extraction and consistent outcome data, is necessary before making a definitive claim about the effectiveness of digital-technology-assisted PBL.

CONCLUSION

This systematic literature review indicates that digital technology can strengthen Problem-Based Learning (PBL) when it supports inquiry, evidence evaluation, collaboration, and the explanation of solutions. In the studies with accessible numerical results, online PBL increased the experimental group's mean critical-thinking score from 59.83 to 75.67, compared with 52.96 to 64.07 in the control group (Rejeki et al., 2022). In a computer-simulation-supported PBL study, the experimental mean rose from 38.93 to 74.45, while the control mean increased from 36.25 to 53.95 (Simanjuntak et al., 2020). Other studies reported significant improvement with augmented reality, digital storytelling, and online PBL, although several did not provide complete score data.

Conceptually, these findings suggest that digital tools are most useful when they make problems accessible, enable exploration, or help learners examine and communicate evidence. Their presence

alone does not ensure critical-thinking development; outcomes depend on instructional design, teacher guidance, learner participation, and the quality of assessment. The evidence is promising but heterogeneous, and the available results cover seven studies with verifiable details rather than the full ten articles specified in the review method. Therefore, conclusions about the overall effectiveness and magnitude of impact should remain provisional until all ten studies are extracted and compared using consistent outcome data.

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