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Role of Electronic Modules Based on Problem-Based Learning Model to Facilitate Critical Thinking Ability: A Systematic Literature Review

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ABSTRACT

Critical thinking is a 21st-century skill that students must master, especially in physics learning, which requires logical reasoning and problem-solving. However, students' critical thinking abilities remain relatively low. One solution proposed by many researchers is an electronic module (e-module) integrated with the Problem-Based Learning (PBL) model. This article aims to systematically examine the role of PBL-based e-modules in facilitating students' critical thinking through a Systematic Literature Review (SLR). The literature review previous studies on PBL-based e-modules across physics, chemistry, biology, and mathematics education, with physics contributing the largest share. A total of 15 journal articles were selected and review based on predetermined inclusion criteria. The findings show that e-modules developed using PBL syntax consistently improve students' critical thinking ability, with N-Gain scores in the moderate, high, and effective categories. These e-modules have also been reported as very valid and very practical for secondary school learning across all four subjects. The integration of real-world problems, active learning activities, and digital features enables students to analyze, evaluate, and solve problems more effectively. Therefore, PBL-based e-modules can serve as an innovative digital teaching resource to strengthen students' critical thinking ability and support student-centered learning in the digital era.

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INTRODUCTION

Twenty first century demands that students possess far more complex ability than simply memorizing course material. One such essential skill is critical thinking, which means they must be able to analyze data, formulate problems, logically evaluate arguments, and draw sound conclusions. According to Tugirin et al., (2025) despite the many different definitions of critical thinking, its foundation remains a reflective thinking process involving analysis, evaluation, and reasoned decision-making about relevant issues. Kirk et al., (2023) added that critical thinking ability should be instilled from an early age through inquiry-

based educational methods. This will teach students to consider phenomena holistically rather than simply memorizing information. They believe that critical thinking, creativity, communication, and collaboration are four core ability of the twenty-first century. Furthermore, Miller et al., (2025) emphasized that these competencies need to be developed systematically through appropriate curricula, assessment practices, and supportive learning environments across different levels of education.

Critical thinking plays an essential role that extends beyond the classroom, as it enables individuals to make informed decisions, evaluate information objectively, and solve problems encountered in both academic and everyday life. Miller et al., (2025) emphasized that critical thinking is one of the core competencies certified and promoted for the future of work, alongside creativity, communication, and collaboration. In the context of education, students with strong critical thinking ability are better prepared to analyze scientific phenomena, assess the validity of arguments, and construct evidence-based conclusions rather than merely memorizing facts. Without deliberate training, however, this ability tends to remain underdeveloped, particularly in subjects that demand analytical reasoning, such as physics. Therefore, cultivating critical thinking from an early stage of education is crucial to preparing students who are able to face the complex problems of the 21st century.

Because physics is full of abstract concepts, mathematical equations, and natural phenomena that require logical reasoning to understand, critical thinking is crucial in physics education. According to research, high school students' ability to think critically about physics remains low. Results from the Program for International Student Assessment (PISA) show that Indonesian students still have a low level of science literacy compared to the OECD average (OECD, 2023). A similar pattern is also visible at the classroom level Rahmadita et al., (2021) profiled the critical thinking skills of high school physics students on dynamic electricity material and found that, although most students fell into the moderate category, a considerable number of them were still classified as low, confirming that the gap identified by international assessments such as PISA also shows up in everyday physics classrooms. This problem is exacerbated by physics instruction that remains dominated by lecture-based methods and routine problem-solving exercises, resulting in students rarely being trained to analyze problems in depth.

One effort to address this problem is by providing open learning materials that facilitate students in developing critical thinking skills. One such learning material is the electronic module (e-module), which is systematically designed as a digital teaching resource that can be used independently by students. Interactive e-modules integrate multimedia elements, such as text, images, and other interactive features, making learning more engaging, effective, and efficient while supporting independent learning (Wijaya & Vidianti, 2020). Research shows that physics e-modules elevate students' critical thinking ability, as demonstrated by the following studies.

Latifah et al., (2020) developed an electronic physics module using Kvisoft Flipbook Maker and found that it improved students' critical thinking skills, with a moderate N-Gain score of 0.602. A similar conclusion was reached by Kurniawan & Syafriani, (2021), whose guided-inquiry e-module proved effective and practical for online physics classes, and by Cahyanto et al., (2022), whose interactive e-module on sound waves raised students' critical thinking N-Gain by 68% at the moderate achievement level. Fitriani et al., (2023) developed a STEM-integrated physics e-module and found a significant difference in critical thinking ability between students who used it and those who did not. Putri & Wahyuni, (2023)

reinforced these findings through a SETS-based physics e-module, showing that linking physics material to real-life problems facilitated students' critical thinking. Sari et al., (2023) reviewed fifteen articles from 2014 to 2023 and found that PBL consistently improved physics learning outcomes, especially on topics like temperature and heat, showing that PBL-based materials can be pedagogically strong even before being tested specifically for critical thinking. Adding to this body of evidence, Andriani et al., (2024) designed a PBL-based physics e-module and found that it significantly improved students' learning outcomes, reinforcing that e-modules built around PBL syntax are a promising vehicle for strengthening physics learning, including critical thinking.

While electronic modules are useful tools, they cannot boost critical thinking skills without an appropriate learning model. The PBL approach fills this gap by training students to think critically and solve authentic, real-world problems. Mutiara et al., (2024) As demonstrated by a comprehensive review of twenty articles discussing PBL adaptations focused on critical thinking, PBL has consistently proven to be a successful method for improving students' critical thinking ability. However, how the PBL syntax is modified to meet students' needs significantly impacts the rate of improvement in students' critical thinking ability. Students face real-world problems early in the learning process before acquiring new knowledge, according to the review. This encourages them to actively explore and collaborate. The PBL syntax—which begins with problem orientation, learning organization, investigation, presentation of work, and evaluation—naturally trains students in the stages of critical thinking, from identifying the problem to evaluating and refining the solutions they ultimately propose.

Previous research has extensively studied the integration of PBL models and electronic modules. Rohmatin et al. (2022) used the Problem-Based Learning (PBL) model to design a flipbook-based e-module aimed at enhancing students' critical thinking ability. The validation results showed a media feasibility rate of 85.43% and a content feasibility rate of 75.41%. Sujanem et al. (2022) found that the Physics-Based Electronic Problem-Solving (PhET) simulation improved critical thinking levels of high school students explained by a moderate average N-Gain score of 0.6. A recent study also found similar result by Janati et al. (2025) similarly showed that a problem-based learning (PBL) model supported by e-modules increased students' critical thinking skills through its implementation. The final examination data revealed a clear performance gap between the two cohorts, with the experimental class securing an average score of 82, outperforming the control group's average of 74.

The results of a meta-analysis conducted by Lu et al., (2025) an analysis of 25 experimental studies on Problem-Based Learning (PBL) shows that using this model can significantly improve students' critical thinking ability, with relatively high effect sizes in physics education. Hafizah et al., (2024) Moreover, as shown by additional meta-analyses, PBL consistently improves students' critical thinking ability across educational levels. In other words, according to research by Rahmat et al., (2020), integrating problem-based learning (PBL) with electronic modules significantly enhances students' critical thinking skills when measured against the conventional instructional methods deployed in control classrooms.

Although PBL-based e-modules have been studied individually, few studies synthesize these findings into a single comprehensive review. This synthesis is crucial for understanding how well such e-modules support critical thinking and for identifying patterns and gaps for future research. This study organizes its results into two phases: designing physics e-modules and implementing an online PBL model that incorporates them, ultimately

showing how online problem-based e-modules enhance students' critical thinking. This structure allows the review to first establish how physics e-modules are typically designed before showing how those design principles translate into an online PBL implementation, and only then to interpret how both phases jointly enhance students' critical thinking.

METHODS

Employing a Systematic Literature Review (SLR) approach, this paper systematically filters, appraises, and consolidates relevant historical literature to map the evolution of the research domain with high structural clarity. SLR differs from conventional literature review methods because it uses more systematic and rigorous steps during the process of identifying, selecting, and evaluating articles, resulting in more valid and reliable results (Pantic & Hamilton, 2024). This approach was chosen because it allows the research questions on PBL-based e-modules and critical thinking ability to be answered through a transparent and replicable process rather than a narrative summary alone. The following sections describe the article selection criteria, search strategy, and data analysis procedure used in this study

The article selection process applied five standards to determine which articles were eligible for review. First, each article had to show direct relevance to critical thinking, PBL, or e-module development. Second, it had to be published in a reputable national or international peer-reviewed journal with available full-text access. Third, publication had to fall between 2018 and 2026 so that the review captured recent developments in the field. Finally, articles were restricted to those written in English or Indonesian.

The first step in the SLR process was searching for articles through the Google Scholar and SINTA (Science and Technology Index) databases. These two databases were selected because they provide broad coverage of nationally and internationally indexed, peer-reviewed journal articles relevant to educational technology and problem-based learning research. The keywords used were “e-module,” “problem-based learning,” and “critical thinking.” The search was conducted using the Boolean AND operator to combine these keywords and was limited to articles published between 2018 and 2025 to ensure the currency of the literature reviewed. In the initial search, hundreds of articles were found, requiring further screening in accordance with the PRISMA (Rizkya et al., 2025).

Screening was based on title relevance, availability of full text, and year of publication. Articles that were irrelevant, not available in full text, or published before 2018 were excluded. The next step was to assess the eligibility of the articles that passed the screening to ensure the appropriateness of the methodology, research background, and their relevance to the research objectives. This screening process yielded fifteen highly relevant articles that fully align with the study's scope, providing a robust empirical baseline for the thematic analysis (Ghamrawi et al., 2025).

The article selection process followed a structured, multi-stage screening procedure adapted from the PRISMA guidelines to ensure transparency and reproducibility. This procedure began with the retrieval of records from the database, followed by successive screening, eligibility assessment, and final inclusion steps, so that only the most relevant and methodologically sound articles were retained. The flowchart below illustrates each stage of this SLR article selection process in detail can be seen in Figure 1.

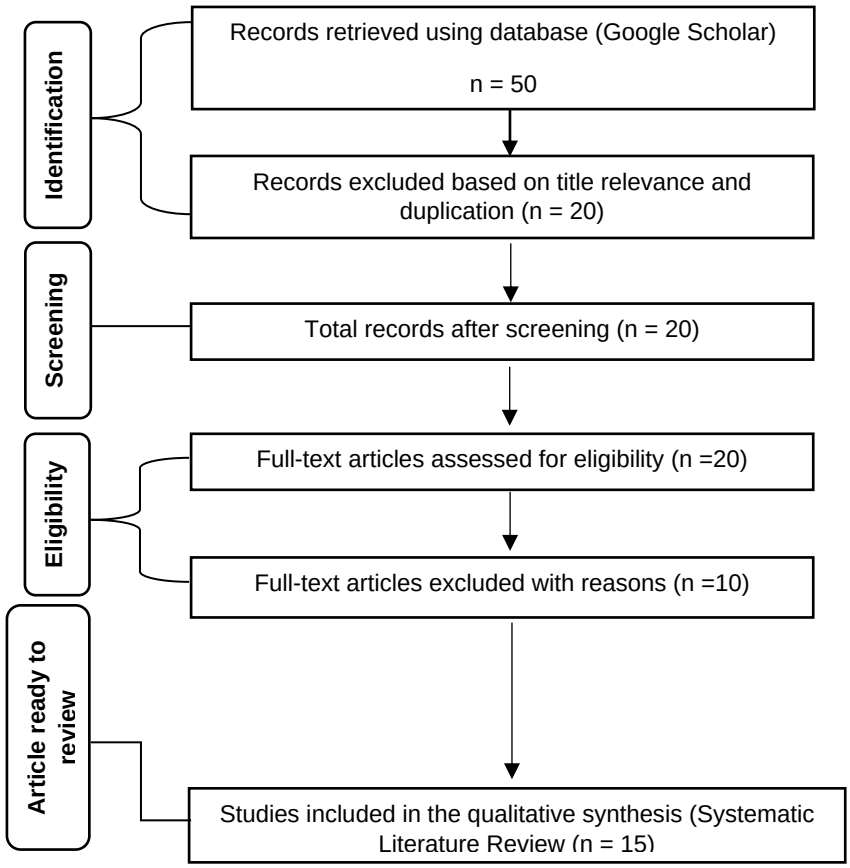

Figure 1. Flowchart of the Literature Selection Process

This diagram shows how the selection process was carried out in a step-by-step and methodical manner to ensure that the reviewed articles were of the highest quality and truly relevant. The data analysis conducted in this SLR study included categorizing the articles according to topic, research methodology, research subjects, and outcomes related to critical thinking ability. The analysis process used a descriptive qualitative approach, focusing on the discovery of innovations and research comparisons. This analytical strategy was also adopted by Hidayat et al., (2023) in their review of educational development trends in Indonesia. This structured process helped ensure that the conclusions drawn from the fifteen selected articles were both systematic and grounded in comparable analytical criteria.

RESULTS AND DISCUSSION

Results

This study identified and analyzed fifteen articles that examined the relationship between the use of problem-based learning models and critical thinking ability. These articles were published between 2020 - 2025 and included both printed learning materials and e-modules. The criteria used to select the papers were relevance, originality, and direct relevance to the research focus. Recent literature underscores critical thinking as a definitive 21st-century skill that requires active refinement. To support its development, modern educational frameworks must leverage innovative models, such as problem-based learning, interactive e-modules, or a blended combination of both approaches.

To provide a general overview before discussing each article in depth, Table 1 summarizes the identity, field, type of electronic teaching material, learning model,

supporting combination, and topic of the fifteen articles analyzed in this review. The articles are ordered by field, from physics to chemistry, biology, and mathematics. This table is intended to give readers a quick reference before the more detailed discussion of individual studies that follows. The identity column lists the author and year of publication of each article, while the field column indicates the subject area in which the e-module was developed and tested. The remaining columns describe the type of teaching material used, the learning model applied, any supporting digital tool, and the specific topic addressed in each study.

Table 1. General Analysis and Grouping of the Reviewed Articles

No	Identity	Field	Model	Combination	Material/Topic
1	Maryani et al., (2026)	Physics	PBL	-	Static Electricity
2	Wiandari et al., (2023)	Physics	PBL	-	Static Fluids
3	Gita et al., (2022)	Physics	PBL	-	Rotational Equilibrium and Dynamics
4	Ainurro'sydah et al., (2024)	Physics	PBL	Google Collaboratory	Motion and Force
5	Harahap & Panggabean, (2026)	Physics	PBL	-	Static Fluids
6	Sari et al., (2022)	Physics	PBL	STEM-Integrated LMS	Harmonic Vibration
7	Asmi et al., (2024)	Chemistry	PBL	-	Electrolytes
8	Wiranti et al., (2022)	Chemistry	PBL	Ispring	Redox Reactions
9	Safitri et al., (2024)	Chemistry	PBL	Chemistry Comic	Reaction Rate
10	Anggraini & Trimulyono, (2025)	Biology	PBL	-	Virus
11	Sartika et al., (2024)	Biology	PBL	-	Human Digestive System
12	Khasanah & Indah, (2024)	Biology	PBL	-	Biodiversity
13	Megawati et al., (2026)	Biology	PBL	-	Circulatory System
14	Rohmatulloh et al., (2023)	Mathematics	PBL	-	General
15	Musaad & Suparman, (2023)	Mathematics	PBL	-	Plane Geometry

Based on Table 1, the fifteen articles analyzed in this review span four different subject areas: physics (six articles), chemistry (three articles), biology (four articles), and mathematics (two articles). All of them develop electronic teaching materials in the form of e-modules integrated with the Problem-Based Learning (PBL) model. Physics contributes the largest share of the reviewed articles, consistent with this study's primary focus, while chemistry, biology, and mathematics each make a smaller but still meaningful contribution. Several e-modules were developed with specific digital tools, such as Ispring, Google Collaboratory, a STEM-integrated LMS, and a chemistry comic, while most reviewed articles reported no specific supporting application. This variation shows that although PBL is applied consistently

as the underlying learning model, its delivery through e-modules differs depending on the subject matter and each team's technological resources.

Before the fifteen articles were selected through the PRISMA screening process described above, a preliminary bibliometric search was conducted on the Scopus database using the keywords "E-module" and "Problem-Based Learning" to map the research landscape on this topic. This search retrieved 50 documents published between 2018 and 2025. Figures 2 to 4 present the distribution of these 50 documents by year, subject area, and country, as retrieved directly from the Scopus Analyze Search Results feature. This preliminary mapping was intended to situate the fifteen selected articles within a broader international research landscape before turning to the detailed content analysis.

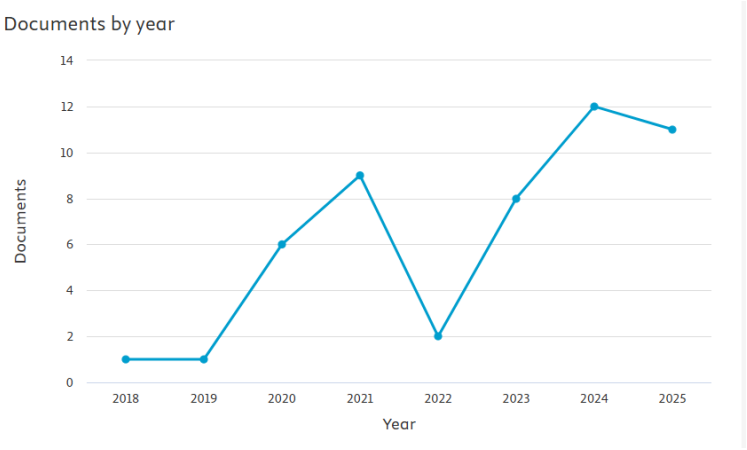

Figure 2. Scopus Documents by Year of Publication (2018-2025)

Figure 2 shows that the number of documents indexed in Scopus for this topic increased considerably over time, from only one document in 2018 and 2019 to a peak of twelve documents in 2024. Aside from a temporary decline in 2022 (two documents), the overall trend confirms that research combining e-modules and Problem-Based Learning has grown substantially in recent years, supporting the relevance and timeliness of this review. This upward trajectory suggests a growing recognition among researchers of the pedagogical value of combining e-modules with the PBL model. It also indicates that the topic remains highly relevant for continued investigation, particularly as recent publication counts continue to rise.

Beyond the publication trend over time, it is also important to understand which academic disciplines have contributed most to this body of research. This is examined by classifying the fifteen selected documents according to the Scopus subject area classification. This classification provides insight into the extent to which research on PBL-based e-modules and critical thinking remains concentrated within science-related disciplines or has begun to expand into the social sciences and other fields. The distribution of documents by subject area is presented in Figure 3.

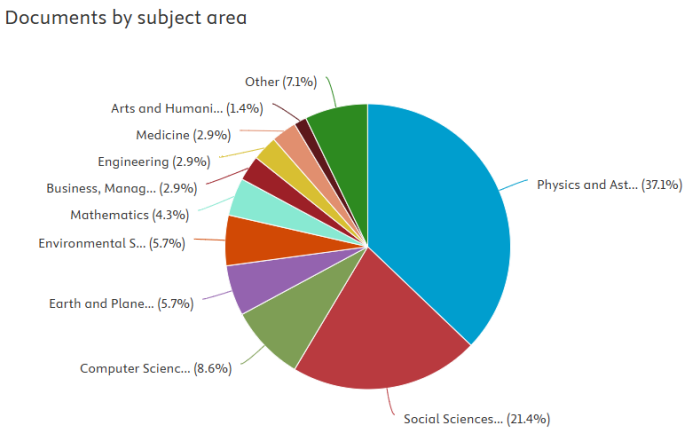

Figure 3. Scopus Documents by Subject Area

Figure 3 shows that Physics and Astronomy accounts for the largest share of documents (26 documents, 37.1%), followed by Social Sciences (15 documents, 21.4%) and Computer Science (6 documents, 8.6%). Smaller shares came from Earth and Planetary Sciences, Environmental Science, Mathematics, Business and Management, Engineering, Medicine, and Arts and Humanities. This distribution confirms that Physics is the most common subject area in which PBL-based e-module research is conducted, which is consistent with the focus of this review. This concentration in Physics and Astronomy aligns with the disciplinary composition of the fifteen articles selected for in-depth review in this study.

In addition to the subject area classification, the geographical origin of the selected documents was also examined to determine where research on PBL-based e-modules and critical thinking is most actively conducted. This analysis was based on the country or territory affiliation of the authors of the fifteen documents indexed in Scopus. Mapping this distribution helps identify whether the topic has been studied broadly across countries or remains concentrated in a small number of research communities. The distribution of documents by country or territory is presented in Figure 4.

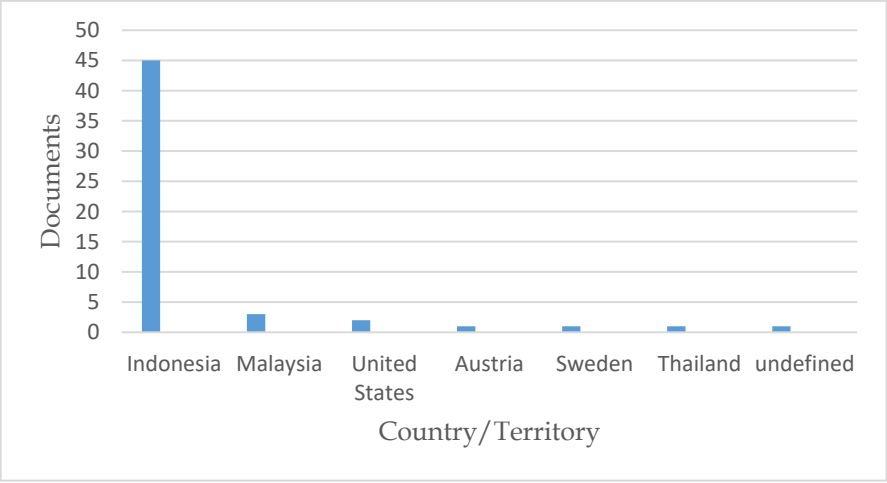

Figure 4. Scopus Documents by Country/Territory

Figure 4 shows that Indonesia contributed the overwhelming majority of Scopus-indexed documents, with 45 documents, which is roughly six times the combined total of all other countries. Malaysia ranked second with three documents, followed by the United States

with two documents, while Austria, Sweden, and Thailand each contributed one document. This indicates that research on this topic remains heavily concentrated within the Indonesian academic community. Because the fifteen articles reviewed in depth in this study are also dominated by Indonesian authors, this concentration points to a need for more cross-country collaboration and comparative studies in the future to test whether these findings also apply in other educational systems.

Having examined the bibliometric characteristics of the reviewed literature, attention now turns to the substantive findings reported across the fifteen articles. Table 2 presents the quantitative validity, practicality, and N-Gain results that were explicitly reported in each reviewed article, together with their corresponding qualitative categories. This table complements Table 1 by focusing specifically on the outcome measures used to evaluate the quality and effectiveness of each e-module. By presenting validity, practicality, and N-Gain side by side, Table 2 makes it possible to compare how consistently the reviewed e-modules perform across these three indicators.

Table 2. Reported Validity, Practicality, and Improvement Results

Learning Material	Validity Score	Category	Practicality Score	Category	N-Gain	Category
Static Electricity	0.84	Valid	92.45%	Very Practical	0.58	Effective
Static Fluids	90.27%	Very Valid	95%	Very Practical	0.72	Moderate
Rotational Equilibrium and Dynamics	3.75	Very Valid	3.50	Very Practical	0.41	Moderate
Motion and Force	88%	Very Valid	90%	Very Practical	0.60	Moderate
Static Fluids	84%	Very Valid	85.5%	Very Practical	0.8	High
Harmonic Vibration	89%	Valid	80%	Practical	0.54	Moderate
Electrolytes	82.75%	Very Valid	93.12%	Very Practical	0.48	Moderate
Redox Reactions	98.09%	Very Valid	4.56	Very Practical	0.90	High
Reaction Rate	4.3	Very Valid	4.3	Very Practical	0.79	Effective
Virus	95%	Very Valid	98%	Very Practical	0.7	High
Human Digestive System	85%	Very Valid	81.06%	Very Practical	0.5	Moderate
Biodiversity	91.4%	Very Valid	97.2%	Very Practical	0.44	Moderate
Circulatory System	95.49%	Very Valid	92.89%	Very Practical	0.72	High
General	80.42%	Very Valid	84.60%	Very Practical	0.5	Moderate
Plane Geometry	4.6	Very Valid	93%	Very Practical	0.683	Moderate

As shown in Table 2, all fifteen articles reported explicit numeric results for validity, practicality, and N-Gain. Validity scores predominantly fall into the "very valid" category (80.42%–98.09%, or 3.75–4.6 on a five-point scale), with only one article (harmonic vibration) rated simply "valid." Practicality scores follow the same pattern—almost all "very practical" (81.06%–98%) except one rated "practical" (80%). For N-Gain, two articles reached "effective" (static electricity, reaction rate), four reached "high" (virus, redox reactions, static fluids, circulatory system), and the remaining nine fell into the "moderate" category. Overall, the reviewed e-modules consistently meet the valid-and-practical standard, with improvements ranging from moderate to effective.

The six physics articles reviewed in this group show consistent and robust results, indicating that PBL-based e-modules can effectively improve students' critical thinking ability across various physics topics. Maryani et al., (2026) developed a PBL e-module on static electricity that achieved a validity score of 0.84, a practicality score of 92.45%, and an N-Gain of 0.58, classified as effective. This finding is consistent with a needs analysis by Reihan et al., (2025), who reported that students still relied on printed worksheets lacking Problem-Based Learning integration on static electricity material. They recommended a PBL-based E-LKPD equipped with animation, video, and simulation to support critical thinking, suggesting that Maryani et al., (2026) addressed a real need already identified in the field. Wiandari et al., (2023) and Harahap & Panggabean, (2026), both working on static fluids, reported very valid and very practical modules with N-Gain scores of 0.72 and 0.8, respectively, indicating moderate-to-high improvement. These early results already indicate that PBL-based e-modules can be adapted to a wide range of physics topics without sacrificing either their validity or their practicality as instructional materials.

Three additional physics articles reinforce this pattern across differing topics. Gita et al., (2022),examining rotational equilibrium and dynamics, reported a very valid and very practical e-module with a moderate N-Gain of 0.41. Ainurro'sydah et al., (2024), who integrated Google Collaboratory into a PBL e-module on motion and force, obtained a very valid and very practical module with a moderate N-Gain of 0.60. Sari et al., (2022) combined a PBL e-module with a STEM-integrated LMS on harmonic vibration, yielding a valid, practical module with a moderate N-Gain of 0.54. The most striking commonality among these six physics articles is a recurring pattern: regardless of topic, PBL-based e-modules consistently achieve very valid and very practical status, with critical-thinking improvement ranging from moderate to effective.

A review of the three chemistry articles discussed above consistently shows that the PBL model is also an effective and reliable approach for developing chemistry e-modules. Asmi et al., (2024) developed a PBL e-module on electrolytes that was very valid (82.75%) and very practical (93.12%), with a moderate N-Gain of 0.48. Wiranti et al., (2022), supported by Ispring, reported the highest validity and practicality scores in this entire review—98.09% and 4.56, respectively—for a redox reaction module, along with a high N-Gain of 0.90. Safitri et al., (2024) combined a chemistry comic with a PBL e-module on reaction rate, achieving very valid and very practical results with an effective N-Gain of 0.79.

Four biology articles extend this pattern beyond the exact sciences. Anggraini & Trimulyono, (2025), Sartika et al., (2024), Khasanah & Indah, (2024), and Megawati et al., (2026) examined biology e-modules covering virus, the human digestive system, biodiversity, and the circulatory system, and their results consistently show that these well-designed PBL-based modules meet the criteria of validity, practicality, and effectiveness. Anggraini & Trimulyono, (2025), reported a high N-Gain of 0.7 for a very valid (95%) and very practical (98%) module

on virus, while Megawati et al., (2026) similarly found a high N-Gain of 0.72 for students' critical thinking using a PBL e-module on the circulatory system. Sartika et al., (2024) and Khasanah & Indah, (2024) each reported moderate N-Gain scores (0.5 and 0.44) alongside very valid and very practical modules

The pattern of strong validity and practicality observed in physics, chemistry, and biology extends equally well to mathematics. Rohmatulloh et al., (2023) and Musaad & Suparman, (2023) are the two mathematics articles, on general mathematics and plane geometry respectively, with moderate N-Gain scores of 0.5 and 0.683. Both confirm that the very valid and very practical status seen in physics, chemistry, and biology extends to mathematics, reinforcing the cross-disciplinary flexibility of the PBL syntax. Overall, the fifteen articles across all four subject areas indicate that PBL-based e-modules consistently meet the criteria of validity, practicality, and effectiveness.

Discussion

Students' critical thinking improved significantly through PBL-based e-modules across all four subject areas—physics, chemistry, biology, and mathematics—consistent with previous research. Rahmat et al., (2020) found a significant increase in critical thinking with PBL-assisted e-modules versus conventional teaching, and recent large-scale reviews confirm this trend. Lu et al., (2025) analyzed 25 separate experimental studies and concluded that the PBL model carries a high effect size for critical thinking development. Hafizah et al., (2024) reached a similar conclusion in their meta-analysis, showing that PBL strongly supports critical thinking, problem-solving skills, and independent learning habits.

The main strength of the reviewed studies lies in integrating digital media into the PBL framework, strengthening students' problem-oriented processes and independent inquiry. Wiranti et al., (2022), for example, combined Ispring with a PBL e-module on redox reactions and obtained the highest validity and practicality scores among the fifteen articles (98.09%, 4.56). Similarly, Ainurro'sydah et al., (2024) used Google Collaboratory to support a PBL e-module on motion and force, while Sari et al., (2022) combined a STEM-integrated LMS with a module on harmonic vibration. Both studies show that embedding computational or web-based platforms into e-modules helps students manipulate variables and observe cause-and-effect relationships more concretely, reinforcing that a PBL-based e-module's success depends on both teaching method and media quality across all four subject areas.

In addition, several of the fifteen reviewed articles found that students' abilities to analyze, interpret, and evaluate through inquiry and reflection activities were enhanced by a Problem-Based Learning (PBL)-based electronic module that covered real-world phenomena. Wiandari et al., (2023) and Harahap & Panggabean, (2026), for instance, independently developed e-modules on static fluids that both achieved very valid and very practical status. This shows that everyday physics phenomena are well suited as authentic PBL problems. Subgroup analyses in an external meta-analysis align with this pattern: Lu et al., (2025) found that PBL yields high effect sizes in physics, mathematics, geography, and science, but not in subjects such as accounting. These findings help explain why the fifteen reviewed articles concentrate on topics rich in observable phenomena—from static fluids and motion in physics, to redox reactions and electrolytes in chemistry, to the digestive and circulatory systems in biology. Such topics are naturally suited to serve as authentic problems during the PBL orientation phase, which Mutiara et al., (2024) identified as key to successfully adapting PBL toward critical thinking.

Because Table 2 reports only validity, practicality, and N-Gain scores without detail on research design, evidentiary strength cannot be fully compared across studies. This review nonetheless shows that quasi-experimental designs with comparison groups, such as those

by Rahmat et al., (2020) and Janati et al., (2025) tend to yield methodologically stronger evidence than single-group designs. Studies that compare an experimental class against a control class, such as the 82 versus 74 result reported by Janati et al., (2025), make it easier to attribute improvement specifically to the PBL-based e-module rather than to other factors like maturation or repeated testing. Future researchers should therefore consistently use quasi-experimental designs with control groups, which would allow the findings in Table 2, particularly the nine articles that reported only a moderate N-Gain, to be interpreted with greater confidence.

Overall, this study shows that PBL-based e-modules across all four subject areas help improve students' critical thinking, a key 21st-century competency, consistent with previous studies such as Miller et al., (2025). They are further reinforced empirically by the meta-analyses of Lu et al., (2025) and Hafizah et al., (2024). Across the four subject areas reviewed here, the electronic module is used not only to convey information but also to help students think critically and reason scientifically. This is achieved through a combination of problem-oriented syntax, supporting digital tools such as Ispring, Google Collaboratory, a STEM-integrated LMS, and a chemistry comic, and content rich in authentic phenomena. This study reinforces previous findings while offering a more comprehensive, cross-disciplinary understanding of how subject content, digital media quality, and research design intersect with e-module effectiveness—providing a valuable reference for educators and instructional designers across all four subject areas.

CONCLUSION

A literature review of 15 articles shows that Problem-Based Learning (PBL)-based e-modules consistently play a role in facilitating improvements in students' critical thinking ability. The strength of the PBL model lies in its anchoring framework: by introducing contextual problems, it naturally trains students to approach analysis, evaluation, and decision-making in a logical, systematic, and evidence-based manner. The integration of interactive technologies, such as PhET and Canva, further enhances the quality of the e-modules, making them more valid, engaging, and effective in supporting the development of critical thinking ability. Theoretically, this study contributes by enriching the literature on PBL-based e-modules across the subject areas covered in this review. Practically, the results can serve as a reference for educators and instructional material developers designing e-modules aligned with the independent curriculum. Future research is recommended to employ a stronger research design and examine a wider variety of topics to yield more comprehensive findings with a broader scope of generalization.

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