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Research analysis of critical thinking skills in physics learning in higher education

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Abstract Critical thinking skills are essential competencies in 21st-century education, particularly in physics learning at the higher education level, where students must analyze, evaluate, and solve complex problems systematically. This study aims to map research trends, challenges, and innovative instructional solutions for developing critical thinking skills in physics education through a systematic literature review (SLR) method via the PRISMA protocol. A total of 18 studies published between 2014 and 2024 were systematically collected from the Scopus database and SINTA 1–2 journals. The majority of the research was conducted in Indonesia, with two additional studies from Ethiopia. Most studies have applied quantitative experimental methods, especially pretest–posttest designs, to assess the impact of learning interventions. Several studies have also utilized research and development (R&D) and mixed-method approaches. The analysis revealed diverse instructional models, including project-based learning (e.g., e-STEM, PjBLRBL), blended learning, inquiry-based learning, augmented reality integration, virtual laboratories, and pocket mobile learning. These approaches consistently improved students' critical thinking skills, with N-Gain values ranging from moderate to high. Additional improvements in collaboration, communication, and creativity were also reported. The students' responses to the innovative models were overwhelmingly positive. This review confirms that active, collaborative, project-based, inquiry-oriented, and technology-enhanced learning environments are highly effective in enhancing critical thinking in physics learning.

Keywords: 21st century education, innovative learning models, meta analysis, higher education

1. Introduction

Critical thinking skills are key competencies in 21st-century education that are highly relevant to the challenges of current scientific and technological developments (Gunadi et al., 2022; Rusmin et al., 2024). In higher education, mastering critical thinking skills helps students understand scientific concepts in depth and encourages them to analyze, evaluate, and solve complex problems rationally and systematically (Raj et al., 2022). The concept of critical thinking must be explored through basic thinking concepts. Studies have shown that critical thinking (CT) is essential for success in instructional tasks (D'Alessio et al., 2019; Fong et al., 2017; Veliz & Veliz-Campos, 2019) and for effectiveness and innovation in the workplace (Jafarigohar et al., 2016; Li, 2023). Physics, a discipline based on logic, analysis, and complex problem solving, requires students to understand and apply theoretical concepts in authentic contexts. However, various studies have shown that the development of critical thinking skills in physics learning at the university level is still very rare (Saprudin et al., 2019; Wulandari et al., 2021). This encourages the need for an in-depth analysis of previous studies to map the developments, challenges, and innovative solutions tested in the context of physics learning in higher education.

Physics learning, which is often abstract and theoretical, requires a pedagogical approach that is oriented not only toward mastering concepts but also toward developing high-level thinking skills. In this context, various studies have explored how critical thinking skills can be developed through learning strategies (Hasyim et al., 2024; Prahani et al., 2023), curriculum approaches (Ayçiçek, 2021), and technology integration in physics learning (Amanda et al., 2023; Isnaeni et al., 2021). Physics learning in college can also be implemented via a learning model designed by design because it can provide a concrete and relevant context for students to understand physics concepts.

The findings of this study are scattered across various publications and have not been systematically collected to provide a comprehensive picture of the trends and directions of study development in this field. To answer this need, this study was conducted via the systematic literature review (SLR) approach, where the SLR research method is a systematic and objective method for collecting, evaluating, and synthesizing relevant evidence from various previously published literature sources (Pati & Lorusso, 2018). The selected literature sources that match the required research keywords are then reviewed and identified in a structured manner according to the steps set out in the systematic literature review (SLR) method (Thomé et al., 2016).

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The literature search strategy was carried out through two primary sources: the Scopus database, one of the largest and most reputable academic databases in the world, and Google Scholar, which uses Publish or Perish software.

2. Materials and Methods

The method used in this study is the systematic literature review (SLR) method, which uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol so that the reported results can be more accurate (Liberati et al., 2009; Moher et al., 2009). The results of article reduction via the PRISMA protocol use four stages: identification, screening, eligibility, and inclusion, as shown in Figure 1.

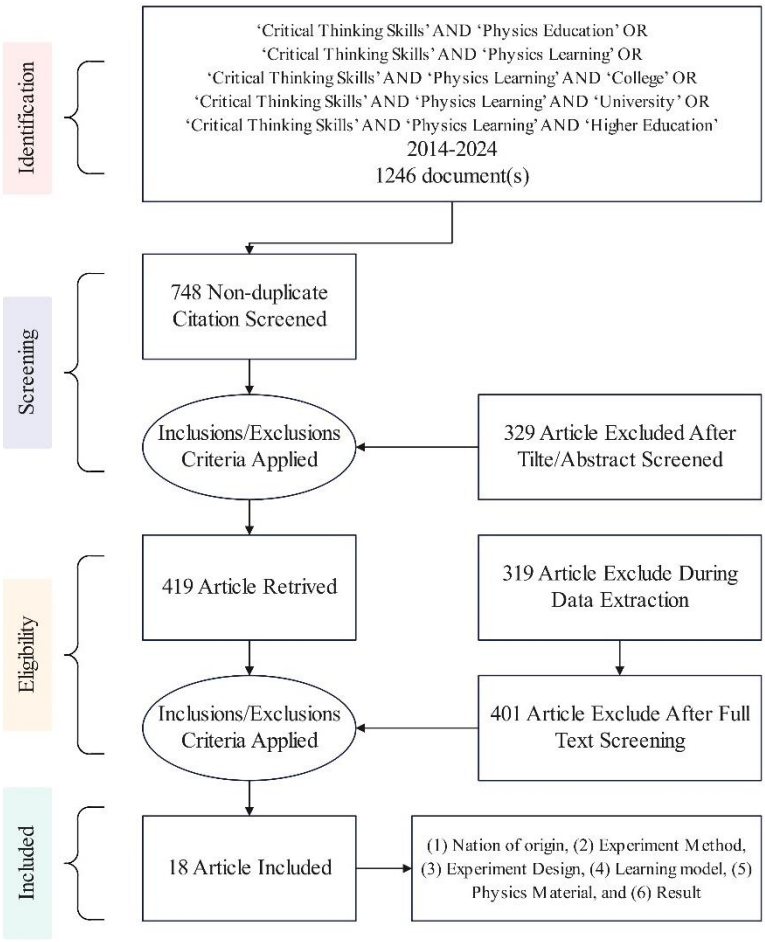

Figure 1 Article reduction flowchart using the PRISMA protocol.

2.1. Eligibility requirements

Improving critical thinking skills in physics learning in higher education is the subject of all initial studies. Studies were identified by looking at relevant publications from the last ten years, from 2024--December 2014, in the Scopus electronic database and SINTA 1–2 journals. All the papers related to the search were written in English and presented scientific research. Journal articles that have completed peer review. The following research journals are examples: International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE), International Journal of Interactive Mobile Technologies (iJIM), Journal of Physics: Conference Series, International Journal of Scientific & Technology Research, International Journal of Learning and Teaching, Journal of Technology and Science Education, International Journal of Science and Mathematics Education, Jurnal Pendidikan IPA Indonesia (JPII) & Jurnal Pelitian Pendidikan IPA (JPIPA)

2.2. Search techniques

In the article search process, keywords that have been arranged logically and combatively to capture maximum relevant coverage are used, namely:

'Critical Thinking Skills' AND 'Physics Education' OR
'Critical Thinking Skills' AND 'Physics Learning' OR
'Critical Thinking Skills' AND 'Physics Learning' AND 'College' OR

'Critical Thinking Skills' AND 'Physics Learning' AND 'University' OR
'Critical Thinking Skills' AND 'Physics Learning' AND 'Higher Education'

This method uses SINTA 1–2 journals and the Scopus digital database. The focus on papers published in Scopus journals and journals in SINTA 1–2 is justified because these publications subject their papers to a rigorous screening process, producing more objective results.

2.3. Process of study selection and data collection

First, each abstract and title were evaluated to determine whether they met the criteria for inclusion. After that, the full texts of the articles were checked to assess their eligibility. The data were collected and analyzed via an Excel spreadsheet from studies that met all the following criteria: (1) nation of origin; (2) experimental method; (3) experimental design; (4) learning model used; (5) physics material taught; and (6) results.

3. Results

3.1. Nation of origin

In terms of country of origin, the results of the article analysis were Indonesia and Ethiopia, which were identified in the search for articles published in the last ten years. The majority of studies were from Indonesia (16 of 18 studies) (Astuti et al., 2018; Dewi et al., 2023; Hartini et al., 2020; Hunaidah et al., 2018; Marnita et al., 2020; Ramadhan et al., 2023; Rohman et al., 2024; Saputro et al., 2022; Serevina et al., 2023a; Sutarno et al., 2019; Verawati et al., 2019, 2021; Wahyudi et al., 2019; Wibowo, 2023; Wibowo et al., 2022; Yulianti et al., 2022), with two additional studies from Ethiopia (2 of 18 studies) (Tiruneh et al., 2016, 2018). This shows that the focus on developing critical thinking skills in physics education is still strong in Indonesia, especially at the university level. Moreover, research from Ethiopia provides an international perspective on the first principles of instruction-based instructional approaches.

3.2. Experimental method

As Figure 2 shows, the research methods used in the studies in this article reflect a strong orientation toward quantitative methods (13 out of 18 studies) (Astuti et al., 2018; Hunaidah et al., 2018; Marnita et al., 2020; Ramadhan et al., 2023; Rohman et al., 2024; Saputro et al., 2022; Tiruneh et al., 2016, 2018; Verawati et al., 2019, 2021; Wahyudi et al., 2019; Wibowo, 2023; Yulianti et al., 2022), especially quasiexperimental methods. Many studies adopt a pretest–posttest design to measure the effectiveness of learning model interventions on physics students' critical thinking skills. This design allows researchers to objectively compare students' initial and final abilities and analyze how much influence the learning model has on improving these abilities. The advantage of this approach lies in its ability to produce strong statistical data that can be generalized in similar contexts.

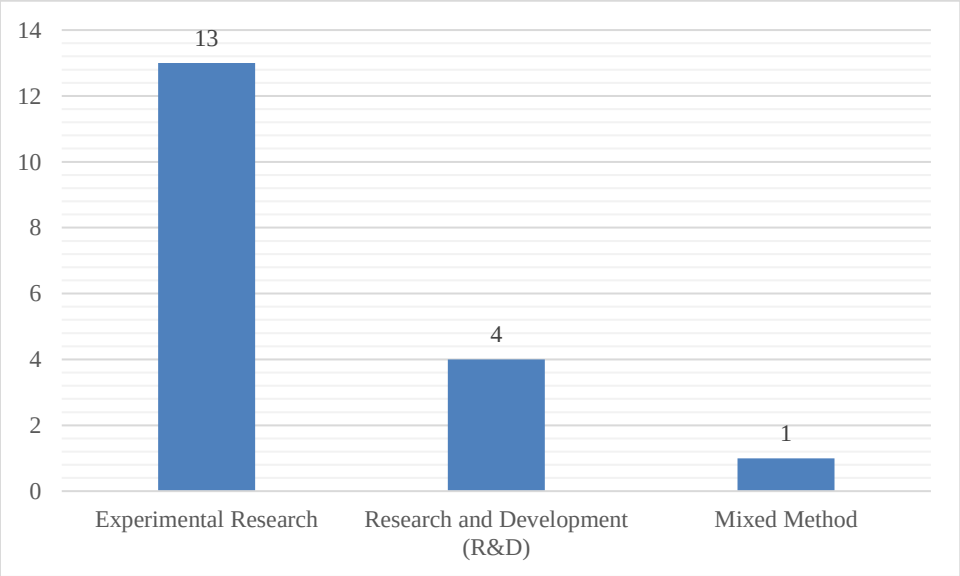

Figure 2 Experimental Method. *Source:* Scopus and Sinta Database.

In addition to the experimental methods, four studies used the research and development (R&D) method (4 of 18 studies) (Dewi et al., 2023; Serevina et al., 2023b; Sutarno et al., 2019; Wibowo et al., 2022). These studies assess effectiveness and design and develop learning tools such as digital books, virtual laboratories, or augmented reality-based applications. The

R&D approach is essential to address the need for innovation in physics education because it can produce ready-to-use learning products that experts have tested validly and reliably. Product validation is important to ensure that the devices developed can improve critical thinking skills.

Moreover, only one study used the mixed method method (Hartini et al., 2020). This method combines quantitative and qualitative data to provide a more comprehensive and in-depth picture of the phenomenon being studied. Although the number is still small, the mixed method approach provides added value because it can explore subjective dimensions that are often overlooked in a purely quantitative approach.

3.3. Experiment Design

As Figure 3 shows, the analysis of the research designs used in the studies of this article revealed that the pretest–posttest one-group design was the most common experimental method (7 out of 18 studies) (Hunaidah et al., 2018; Marnita et al., 2020; Rohman et al., 2024; Verawati et al., 2019, 2021; Wahyudi et al., 2019; Yulianti et al., 2022). This design is used when researchers want to evaluate the direct impact of a learning model on one group of participants without comparing it to a control group. Researchers can observe improvements due to learning interventions by measuring critical thinking skills before and after treatment. The advantages of this design lie in its ease of implementation and its efficiency in terms of time and resources. However, the weakness is the absence of an external comparator, which makes the research results susceptible to the influence of external variables (external validity), so the results must be interpreted carefully.

On the other hand, several studies have applied the pretest–posttest control group design, which is methodologically stronger because it involves an experimental group and a control group (6 out of 18 studies) (Astuti et al., 2018; Ramadhan et al., 2023; Saputro et al., 2022; Tiruneh et al., 2016, 2018; Wibowo, 2023). This design allows researchers to compare learning outcomes between students who receive innovative learning model treatment and those who learn via conventional methods. The results of this design tend to be more generalizable and provide stronger empirical evidence about the effectiveness of a model.

Moreover, studies that use the research and development (R&D) method, especially the ADDIE model, focus not only on measuring effectiveness but also on the process of developing and validating learning products (4 of 18 studies) (Dewi et al., 2023; Serevina et al., 2023b; Sutarno et al., 2019; Wibowo et al., 2022). The systematic ADDIE stages (Analyze, Design, Develop, Implement, Evaluate) allow researchers to ensure that the products produced, whether in the form of digital media, virtual laboratories, or other learning tools, have gone through a multilayered evaluation process before being tested for their effectiveness in improving students' critical thinking.

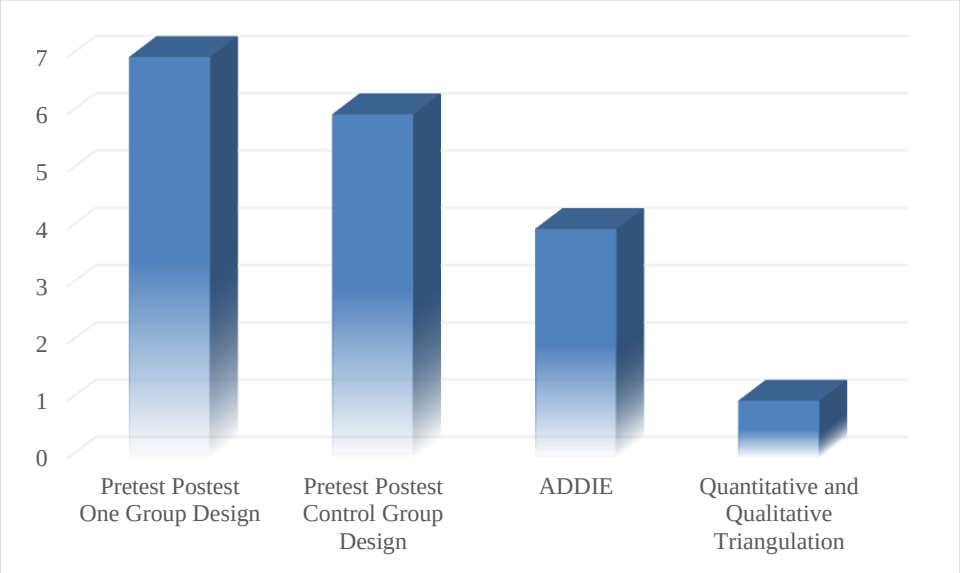

Figure 3 Experiment design. *Source:* Scopus and Sinta Database.

Moreover, studies that use the mixed method method use a qualitative and quantitative triangulation design (Hartini et al., 2020). Through data triangulation, this study not only measures improvements in critical thinking skills through quantitative instruments but also explores students' learning experiences and perceptions of learning.

3.4. Learning model

Table 1 shows that the learning models used in the studies in this article show a high level of diversity and innovation in designing learning experiences that can develop students' critical thinking skills. One of the most prominent models is project-

based learning (PjBL), which is designed by designs such as E-STEM and PjBLRBL, emphasizing contextual learning based on real projects to encourage active engagement and collaborative problem solving. In addition, the blended learning model is an investment choice because it flexibly integrates online and offline learning, allowing students to access materials independently while still receiving direct guidance. Moreover, the inquiry learning model, both reflective and cognitive conflict strategy-based, provides space for students to develop in-depth investigative and self-reflective skills.

Table 1 Learning model.

No	Author	Year	Title	Learning Model
1	Rohman et al.	2024	Effectiveness of Ethnoecological-STEM Project-Based Learning Model to Improve Critical Thinking Skills, Creativity, and Science Concept Mastery	Ethnoecological-Science, Technology, Engineering and Mathematics based on Project Based Learning (E-STEM PjBL) Learning Model
2	Dewi et al.	2023	Project-based Laboratory Rotation Blended Learning Model to Train Students' Critical Thinking and Collaboration in Physics Course	Project-based Laboratory Rotation Blended Learning (PjBLRBL) Model
3	Ramadhan et al.	2023	The Effect of Interface Instrumentation Experiments-Supported Blended Learning on Students' Critical Thinking Skills and Academic Achievement	Blended Learning Based on Interface Instrumentation Experiments
4	Serevina et al.	2023	Development of a tectonic earthquake knowledge enrichment digital book to improve students' critical thinking skill	Interactive Digital Media Development
5	Saputro et al.	2022	Effectiveness of Clarity Learning Model to Improve Students'Advanced Clarification Critical Thinking Ability in Physics Courses	Clarity Learning Model (CLM)
6	Wibowo, F. C.	2022	Effects of Augmented Reality Integration (ARI) based Model Physics Independent Learning (MPIL) for facilitating 21st-Century Skills (21-CS)	Physics Independent Learning (MPIL) model based on Augmented Reality Integration (ARI)
7	Yulianti et al.	2022	Scratch Assisted Physics Learning with a STEM Approach in the Pandemic Era to Develop 21st Century Learning Skills	Science Technology Engineering and Mathematics (STEM) based Problem Based Learning (PBL) and assisted by Scratch
8	Wibowo et al.	2022	Optics Virtual Laboratory (OVL) Based on Physics Independent Learning (PIL) For Improving Critical Thinking Skill	Physics Independent Learning (PIL)
9	Verawati et al.	2021	Reflective Practices in Inquiry Learning: Its Effectiveness in Training Pre-Service Teachers' Critical Thinking Viewed from Cognitive Styles	Reflective-Inquiry Learning
10	Marnita et al.	2020	The Effect of Blended Learning Problem-Based Instruction Model on Students' Critical Thinking Ability in Thermodynamic Course	Problem Based Instruction based on Blended Learning
11	Hartini et al.	2020	Critical Thinking Skills (CTS) and Rigid Object Rotation (ROR) Concept Mastery Through Multiple-Based Representation (MR) in Mechanics Learning Using GeoGebra Software	Multiple-Based Representation (MR)
12	Wahyudi et al.	2019	Effectiveness of Inquiry-Creative-Process Learning Model to Promote Critical Thinking Ability of Prospective Physics Teachers	Inquiry-Creative-Process (ICP) Learning Model
13	Verawati et al.	2019	The Effect of Conflict-Cognitive Strategy in Inquiry Learning toward Pre-Service Teachers' Critical Thinking Ability	Inquiry-Based Learning with Conflict-Cognitive Strategy
14	Sutarno et al.	2019	The development of higher order thinking virtual laboratory on photoelectric effect	Higher Order Thinking Virtual Laboratory (HOT-VLab)
15	Hunaidah et al.	2018	Improving Collaborative Critical Thinking Skills of Physics Education Students through Implementation of CinQASE Learning Model	Collaborative in Questioning, Analyzing, Synthesizing and Evaluating (CinQASE) Learning Model
16	Astuti et al.	2018	The impact of pocket mobile learning to improve critical thinking skills in physics learning	Pocket Mobile Learning

17	Tiruneh et al.	2018	Designing Learning Environments for Critical Thinking: Examining Effective Instructional Approaches	First Principle Instruction Model
18	Tiruneh et al.	2016	Systematic design of a learning environment for domain specific and domain-general critical thinking skills	First Principle Instruction Model

3.5. Physics material

The learning materials used in the research are very varied, covering basic concepts to advanced topics. As figure 4 shows, the distributions of the physics materials used.

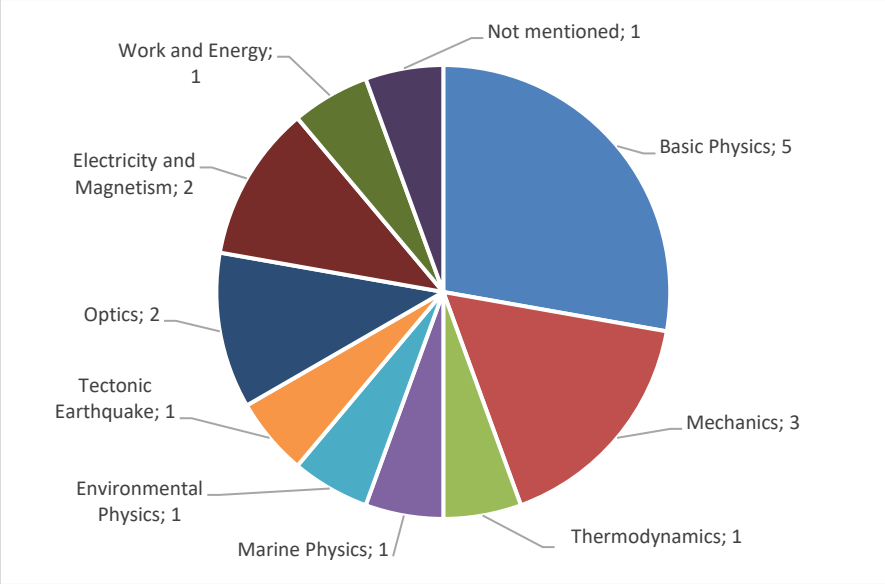

Figure 4 Physics materials. *Source:* Scopus and Sinta Database.

3.6. Results

The results of the analysis of the articles presented in Table 2 show that, overall, all the studies reported a significant increase in critical thinking skills after the implementation of the learning model, as evidenced by an increase in the N-Gain value from the pretest to the posttest, with a moderate to high category. In addition to critical thinking, several studies have measured other 21st-century skills, such as collaboration, communication, and creativity, which have shown promising results. Student responses to innovative learning models were also reported to be very good. These models are academically effective and well received by students.

Table 2 Data related to the research results.

No.	Author	Year	Sample	Instrument	Findings
1	Rohman et al.	2024	The study was conducted through a limited test involving 13 participants and a large-scale test involving 31 participants.	Science concept mastery test Critical thinking skills test Creativity skills observation sheet Expert validation sheet for instruments	There is a significant increase in concept mastery after applying the model. In addition, there is a significant improvement in critical thinking skills, with the most mastered aspects being the ability to provide simple explanations, build basic skills, and organize strategies. Meanwhile, creativity is measured across four aspects, all of which fall into the good category.
2	Dewi et al.	2023	The study involved 50 participants.	Critical thinking assessment tools Collaboration skills assessment sheet	All products were validated by five experts and received an Aiken's V value greater than 0.87, indicating that they were declared valid. Students' critical thinking skills after participating in learning with the PjBLRBL model

					showed a considerable improvement, and their collaboration skills also demonstrated positive results.
3	Ramadhan et al.	2023	The study consisted of an experimental class with 22 participants and a control class with 18 participants.	Critical Thinking Test (CTT) Physics Achievement Test (PAT)	Regarding critical thinking skills, after the treatment, the experimental group achieved a significantly higher score than the control group. In terms of academic achievement, the posttest results showed that the experimental group's academic score was much higher compared to the control group.
4	Serevina et al.	2023	The study involved 49 participants.	Validation instrument Critical thinking test	The digital book designed to enrich knowledge about tectonic earthquakes was developed through the ADDIE stages and successfully passed the expert validation process with an outstanding category. In the critical thinking ability test, the average posttest score showed an improvement.
5	Saputro et al.	2022	The study consisted of an Experimental Class 1 with 24 participants and an Experimental Class 2 with 18 participants.	Advanced clarification critical thinking skills test Validation sheet	There was a significant increase in critical thinking skills in both experimental groups. Most of the critical thinking indicators improved to the high category, with only one remaining in the moderate category. No significant difference was found between the two experimental classes, indicating that the CLM can be effectively applied across different classes with consistent results.
6	Wibowo, F. C.	2022	The study consisted of an experimental class with 44 participants and a control class with 44 participants.	Creative Thinking Skills (CreTS) test Critical Thinking Skills (CriTS) test Collaboration Skills (ColS) test Communication Skills (ComS) test	There was no significant difference between the two groups before the treatment. After the treatment, the experimental group showed a significant increase in all aspects of 21st-century skills compared to the control group. The use of MPIL-based ARI led to higher scores across all aspects of 21st-century skills.
7	Yulianti et al.	2022	The study involved 110 participants.	Descriptive test Observation sheet Questionnaire	Critical thinking showed an increase with N-Gain in the moderate category. Creative thinking also improved with N-Gain in the moderate category. Communication demonstrated an increase, with all indicators falling into the moderate category, while collaboration likewise showed an improvement within the same category. The response to STEM and Scratch-based learning was quite good, with an average score of 77.33%.
8	Wibowo et al.	2022	The study involved 38 participants.	CTS test includes Analysis, Inference,	The study results showed increased students' CTS in the moderate category. It indicates that PIL-based

				and Evaluation indicators Interview	OVL can significantly improve students' critical thinking skills, especially in analysis, inference, and evaluation.
9	Verawati et al.	2021	The study involved 16 participants from UNDIKMA and 18 participants from UNRAM.	GEFT (Group Embedded Figures Test) Critical Thinking Skills Test	Most prospective physics teacher students demonstrated a field-independent (FI) cognitive style rather than a field-dependent (FD) one. The measurement of critical thinking skills revealed that both groups experienced an increase, reaching the "critical" category. When viewed from the perspective of cognitive style, students with both FD and FI tendencies showed improved critical thinking skills, also achieving the "critical" category after learning.
10	Marnita et al.	2020	3rd Semester of the Physics Study Program at the University of Almuslim	Critical Thinking Skills Test Questionnaire	The increase in students' critical thinking skills ranged from moderate to high. Student responses, based on the distributed questionnaire, showed that the majority felt very happy participating in learning with this model, reaching 81%.
11	Hartini et al.	2020	The study involved 21 participants.	ROR concept comprehension test California Critical Thinking Test (CCTT) Critical Thinking Disposition Inventory (CTDI)	The study results indicated a significant improvement in mastery of the ROR concept after the implementation of learning. The MR aspect, analyzed through student work, revealed that representations in images and mathematics were more dominant in helping students understand the ROR concept. In addition, students' critical thinking skills also showed a significant increase, with the average posttest score for this aspect reaching 70.6%.
12	Wahyudi et al.	2019	The study involved 20 participants from UNRAM, 9 participants from IKIP Mataram, 16 participants from UIN Mataram, and 16 participants from UM Mataram.	Critical thinking skills test adapted from the Ennis-Weir Critical Thinking Essay Test	There was an improvement in critical thinking skills, shifting from the not critical category to the critical category with a high n-gain level. Statistical tests (t-tests) revealed a significant increase in critical thinking skills across all groups. The ANOVA test results indicated no significant difference in the improvement between groups, showing that the ICP model was effectively applied in all groups.
13	Verawati et al.	2019	The study involved 18 participants.	Critical Thinking Skills Test	There was an improvement in critical thinking skills, moving from the less critical category to the quite critical category with a moderate N-gain level. The application of cognitive-conflict strategies in inquiry learning had a significant influence on enhancing students' critical thinking skills.

14	Sutarno et al.	2019	The study involved 35 participants.	Critical Thinking Skills (CTS) Test Creative Problem Solving Skills (CPSS) Test	Implementing the HOT-VLab model produced significant results in improving students' higher-order thinking skills. There was also an increase in the average value of critical thinking skills and creative problem-solving skills, with the improvement categorized as moderate. The t-test results revealed a statistically significant difference between the pretest and posttest scores, indicating the effectiveness of this learning model.
15	Hunaidah et al.	2018	The study included Class A with 19 participants, Class B with 19 participants, and Class C with 18 participants.	Direct Assessment of Collaborative Critical Thinking (DACCT) Student response questionnaire	The study results showed high average posttest scores for students' collaborative critical thinking skills. A significant improvement was observed after applying the CinQASE model. The average n-gain score reached 0.62, which falls into the moderate increase category. The ANOVA test results indicated no significant difference between class groups, showing that the improvement was consistent across all. Students' responses to the application of the CinQASE model were also quite positive, with a percentage above 70%.
16	Astuti et al.	2018	The study consisted of an experimental class with 24 participants and a control class with 26 participants.	Multiple choice evaluation questions totaling 20 questions	There was a difference in the average critical thinking skills score between students in the treatment group using Pocket Mobile Learning and those in the control group using PowerPoint, with the treatment group achieving a higher score. Statistical analysis with the ANOVA test showed a significance value of 0.000 ($p < 0.05$).
17	Tiruneh et al.	2018	The study consisted of an Immersion group with 36 participants, an Infusion group with 69 participants, and a Control group with 42 participants.	HCTA (Halpern Critical Thinking Assessment) CTEM (Critical Thinking in Electricity and Magnetism) Academic Achievement Test (Teacher-Made Test)	Students in the Immersion and Infusion groups showed significantly greater improvement in domain-specific critical thinking skills compared to the control group. However, there was no significant difference in the enhancement of domain-general critical thinking when compared with the control. Both the Immersion and Infusion groups also achieved higher academic grades in the course than the control group. No significant difference was found between the Immersion and Infusion groups in terms of content mastery and domain-specific critical thinking skills.

18	Tiruneh et al.	2016	The study consisted of an experimental class with 45 participants and a control class with 44 participants.	HCTA (Halpern Critical Thinking Assessment) CTEM (Critical Thinking in Electricity and Magnetism)	The results indicated that the experimental group achieved significantly better outcomes than the control group in domain-specific critical thinking skills on electricity and magnetism material. For general critical thinking skills, there was no significant improvement between the experimental and control groups from pretest to posttest. Students who demonstrated strong critical thinking performance in the electricity and magnetism domain also tended to perform better in applying critical thinking to everyday life problems.

4. Discussion

On the basis of the results of a study of research articles published in the last 10 years (2014--2024), it can be concluded that applying various innovative learning models can consistently improve critical thinking skills in physics education. Project-based learning models such as ethnoecological-STEM project-based learning (Rohman et al., 2024), project-based laboratory rotation blended learning (Dewi et al., 2023), and the integration of STEM with Scratch (Yulianti et al., 2022) are highly effective in training students' critical thinking skills through real-life and contextual activity-based approaches. Project-based learning is adequate because it encourages students to actively identify problems, explore solutions, and reflect on the results (Zhang & Ma, 2023). The blended learning model combined with an experimental or problem-based approach, such as that developed by Ramadhan et al. (2023) and Marnita et al. (2020), significantly improves critical thinking skills and academic achievement. This approach provides flexibility in learning access and supports deeper conceptual understanding through online and face-to-face learning (Nouby & Alkhazali, 2017). Moreover, the inquiry learning-based approach, both in the form of reflective inquiry (Verawati et al., 2021) and conflict-cognitive-based inquiry (Verawati et al., 2019), has been shown to strengthen students' analytical, inference, and evaluation skills by encouraging them to think critically about the scientific phenomena they face. The use of technology in the independent learning model also has a positive effect on students' critical thinking skills. The implementation of augmented reality integration in independent physics learning (Wibowo, 2023) and the development of the Optics Virtual Laboratory (Wibowo et al., 2022) show that the use of technology-based media can facilitate the learning of abstract concepts more interactively and interestingly. In addition, research (Astuti et al., 2018) related to Pocket Mobile Learning has shown that mobile device-based learning increases the flexibility of learning time and supports students' analytical skills.

Other learning models, such as the Clarity Learning Model (Saputro et al., 2022), CinQASE (Hunaidah et al., 2018), HOT-VLab (Sutarno et al., 2019), and the multiple-based representation approach assisted by GeoGebra (Hartini et al., 2020), enrich the variety of critical thinking development strategies. These models emphasize aspects such as clarity of thinking, collaborative work, creativity in problem solving, and the use of various forms of representation in understanding abstract physics concepts. Findings from studies in Ethiopia (Tiruneh et al., 2016, 2018) also strengthen the argument that the systematic application of the first principles instruction model in electricity and magnetism learning can improve domain-specific critical thinking skills. However, they reported that additional explicit instruction is still needed for domain-general critical thinking skills. Critical thinking skills can be developed effectively through active, collaborative, project-based, inquiry learning, and technology integration in learning (Halpern, 2014). The success of these various learning models reinforces the importance of instructional design, which emphasizes active engagement, problem solving, critical reflection, and technology integration to prepare students for the challenges of the 21st century.

5. Final Considerations

On the basis of the results of the studies of the last 10 years of research (2014--2024) that were analyzed, it can be concluded that applying various innovative learning models can consistently improve students' critical thinking skills in physics education. Project-based learning models, blended learning, inquiry learning, technology-based independent learning, multirepresentation, and virtual laboratory-based models significantly improve critical thinking indicators such as analysis, inference, evaluation, and the development of 21st-century skills, including creativity, collaboration, and communication.

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Ethical Considerations

Not applicable.

Conflict of Interest

We have no conflicts of interest to disclose.

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References

Amanda, F. D., Rahmi, Y., Asrizal, & Akmam. (2023). Meta-analysis: The effect of electronic learning media on students' 21st century skills in the industrial revolution era 4.0. *Jurnal Penelitian Pendidikan IPA, 9*(11), 992–1003. https://doi.org/10.29303/jppipa.v9i11.4361

Astuti, I. A. D., Dasmo, D., Nurullaeli, N., & Rangka, I. B. (2018). The impact of pocket mobile learning to improve critical thinking skills in physics learning. *Journal of Physics: Conference Series, 1114*(1), 012030. https://doi.org/10.1088/1742-6596/1114/1/012030

Ayçiçek, B. (2021). Integration of critical thinking into curriculum: Perspectives of prospective teachers. *Thinking Skills and Creativity, 41,* 100895. https://doi.org/10.1016/j.tsc.2021.100895

D'Alessio, F. A., Avolio, B. E., & Charles, V. (2019). Studying the impact of critical thinking on the academic performance of executive MBA students. *Thinking Skills and Creativity, 31,* 275–283. https://doi.org/10.1016/j.tsc.2019.02.002

Dewi, N. R., Listiaji, P., Akhlis, I., Kurniawan, I. O., Siswanto, & Widyaningrum, R. A. (2023). Project-based laboratory rotation blended learning model to train students' critical thinking and collaboration in physics course. *E3S Web of Conferences, 400,* 01023. https://doi.org/10.1051/e3sconf/202340001023

Fong, C. J., Kim, Y., Davis, C. W., Hoang, T., & Kim, Y. W. (2017). A meta-analysis on critical thinking and community college student achievement. *Thinking Skills and Creativity, 26,* 71–83. https://doi.org/10.1016/j.tsc.2017.06.002

Gunadi, G., Haryono, H., & Purwanti, E. (2022). The analysis of 21st century learning implementation and competency achievement of junior high school students in 3T regions. *Innovative Journal of Curriculum and Educational Technology, 11*(1), 10–18. https://doi.org/10.15294/ijcet.v11i1.44847

Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th ed.). Psychology Press.

Hartini, T. I., Liliasari, S., Setiawan, A., & Ramalis, T. R. (2020). Critical thinking skills (CTS) and rigid object rotation (ROR) concept mastery through multiple-based representation (MR) in mechanics learning using GeoGebra software. *Journal of Physics: Conference Series, 1491*(1), 012019. https://doi.org/10.1088/1742-6596/1491/1/012019

Hasyim, F., Prastowo, T., & Jatmiko, B. (2024). Critical thinking-independent learning: A model of learning to improve students' critical thinking skills. *European Journal of Educational Research, 13*(2), 747–762. https://doi.org/10.12973/eu-jer.13.2.747

Hunaidah, H., Susantini, E., Wasis, W., Prahani, B. K., & Mahdiannur, M. A. (2018). Improving collaborative critical thinking skills of physics education students through implementation of CinQASE learning model. *Journal of Physics: Conference Series, 1108*(1), 012101. https://doi.org/10.1088/1742-6596/1108/1/012101

Isnaeni, W., Sujatmiko, Y. A., & Pujiasih, P. (2021). Analysis of the role of Android-based learning media in learning critical thinking skills and scientific attitude. *Jurnal Pendidikan IPA Indonesia, 10*(4), 607–617. https://doi.org/10.15294/jpii.v10i4.27597

Jafarigohar, M., Hemmati, F., Rouhi, A., & Divsar, H. (2016). Instructors' attitudes towards the reflection of critical thinking in course syllabi: Evidence from an expanding circle. *Theory and Practice in Language Studies, 6*(1), 59–67. https://doi.org/10.17507/tpls.0601.08

Li, L. (2023). Critical thinking from the ground up: Teachers' conceptions and practice in EFL classrooms. *Teachers and Teaching, 29*(6), 571–593. https://doi.org/10.1080/13540602.2023.2191182

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *PLoS Medicine, 6*(7), e1000100. https://doi.org/10.1371/journal.pmed.1000100

Marnita, M., Taufiq, M., Iskandar, I., & Rahmi, R. (2020). The effect of blended learning problem-based instruction model on students' critical thinking ability in thermodynamic course. *Jurnal Pendidikan IPA Indonesia, 9*(3), 430–438. https://doi.org/10.15294/jpii.v9i3.23144

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Nouby, A., & Alkhazali, T. (2017). The effect of designing a blended learning environment on achievement and deep learning of graduate students at the Arabian Gulf University. *Open Journal of Social Sciences, 5*(10), 248–260. https://doi.org/10.4236/jss.2017.510022

Pati, D., & Lorusso, L. N. (2018). How to write a systematic review of the literature. *HERD: Health Environments Research & Design Journal, 11*(1), 15–30. https://doi.org/10.1177/1937586717747384

Prahani, B. K., Jatmiko, B., Pristianti, M. C., Satriawan, M., Amelia, T., & Makahinda, T. (2023). The dHOTLearn model to improve critical thinking skills of physics education program undergraduate. *Journal of Higher Education Theory and Practice, 23*(19), 120–131. https://doi.org/10.33423/jhetp.v23i19.6676

Raj, T., Chauhan, P., Mehrotra, R., & Sharma, M. (2022). Importance of critical thinking in the education. *World Journal of English Language, 12*(3), 126–133. https://doi.org/10.5430/wjel.v12n3p126

Ramadhan, M. F., Mundilarto, M., Ariswan, A., Irwanto, I., Bahtiar, B., & Gummah, S. (2023). The effect of interface instrumentation experiments-supported blended learning on students' critical thinking skills and academic achievement. *International Journal of Interactive Mobile Technologies, 17*(14), 101–125. https://doi.org/10.3991/ijim.v17i14.38611

Rohman, M. H., Marwoto, P., Nugroho, S. E., & Supriyadi, S. (2024). Effectiveness of ethnoecological-STEM project-based learning model to improve critical thinking skills, creativity, and science concept mastery. *International Journal of Cognitive Research in Science, Engineering and Education, 12*(3), 521–534. https://doi.org/10.23947/2334-8496-2024-12-3-521-534

Rusmin, L., Misrahayu, Y., Pongpalilu, F., Radiansyah, R., & Dwiyanto, D. (2024). Critical thinking and problem-solving skills in the 21st century. *Join: Journal of Social Science, 1*(5), 144–162. https://doi.org/10.59613/svhy3576

Saprudin, S., Liliasari, S., Prihatmanto, A. S., & Setiawan, A. (2019). Profile of pre-service physics teachers' creative thinking skills on wave and optics course. *Journal of Physics: Conference Series, 1157*(3), 032030. https://doi.org/10.1088/1742-6596/1157/3/032030

Saputro, S., Tukiran, & Supardi, Z. (2022). Effectiveness of clarity learning model: The new model learning to improve critical thinking skills advanced clarification in physics courses. *Pegem Journal of Education and Instruction, 12*(3), 71–82. https://doi.org/10.47750/pegegog.12.03.06

Serevina, V., Lipikuni, H. F., & Maulana, D. (2023). Development of a tectonic earthquake knowledge enrichment digital book to improve students' critical thinking skill. *Journal of Physics: Conference Series, 2596*(1), 012059. https://doi.org/10.1088/1742-6596/2596/1/012059

Sutarno, S., Setiawan, A., Kaniawati, I., & Suhandi, A. (2019). The development of higher order thinking virtual laboratory on photoelectric effect. *Journal of Physics: Conference Series, 1157*(3), 032034. https://doi.org/10.1088/1742-6596/1157/3/032034

Thomé, A. M. T., Scavarda, L. F., & Scavarda, A. J. (2016). Conducting systematic literature review in operations management. *Production Planning & Control, 27*(5), 408–420. https://doi.org/10.1080/09537287.2015.1129464

Tiruneh, D. T., De Cock, M., & Elen, J. (2018). Designing learning environments for critical thinking: Examining effective instructional approaches. *International Journal of Science and Mathematics Education, 16*(6), 1065–1089. https://doi.org/10.1007/s10763-017-9829-z

Tiruneh, D. T., Weldeslassie, A. G., Kassa, A., Tefera, Z., De Cock, M., & Elen, J. (2016). Systematic design of a learning environment for domain-specific and domain-general critical thinking skills. *Educational Technology Research and Development, 64*(3), 481–505. https://doi.org/10.1007/s11423-015-9417-2

Veliz, L., & Veliz-Campos, M. (2019). An interrogation of the role of critical thinking in English language pedagogy in Chile. *Teaching in Higher Education, 24*(1), 47–62. https://doi.org/10.1080/13562517.2018.1456424

Verawati, N. N. S. P., Hikmawati, H., Prayogi, S., & Bilad, M. R. (2021). Reflective practices in inquiry learning: Its effectiveness in training pre-service teachers' critical thinking viewed from cognitive styles. *Jurnal Pendidikan IPA Indonesia, 10*(4), 505–514. https://doi.org/10.15294/jpii.v10i4.31814

Verawati, N. N. S. P., Prayogi, S., Gummah, S., Muliadi, A., & Yusup, M. Y. (2019). The effect of conflict-cognitive strategy in inquiry learning towards pre-service teachers' critical thinking ability. *Jurnal Pendidikan IPA Indonesia, 8*(4), 529–537. https://doi.org/10.15294/jpii.v8i4.21002

Wahyudi, Verawati, N. N. S. P., Ayub, S., & Prayogi, S. (2019). Effectiveness of inquiry-creative-process learning model to promote critical thinking ability of prospective physics teachers. *Journal of Physics: Conference Series, 1417*(1), 012071. https://doi.org/10.1088/1742-6596/1417/1/012071

Wibowo, F. C. (2023). Effects of augmented reality integration (ARI) based model physics independent learning (MPIL) for facilitating 21st-century skills (21-CS). *Journal of Technology and Science Education, 13*(1), 178–190. https://doi.org/10.3926/jotse.1800

Wibowo, F. C., Darman, D. R., Prahani, B. K., & Faizin, M. N. (2022). Optics virtual laboratory (OVL) based on physics independent learning (PIL) for improving critical thinking skill. *Journal of Physics: Conference Series, 2377*(1), 012077. https://doi.org/10.1088/1742-6596/2377/1/012077

Wulandari, R., Jatmiko, B., Budiyanto, M., Hariyono, E., Lestari, N. A., & Prahani, B. K. (2021). A critical thinking skill profile of science education undergraduate student in basic physics. *Journal of Physics: Conference Series, 2110*(1), 012030. https://doi.org/10.1088/1742-6596/2110/1/012030

Yulianti, D., Sugianto, S., & Ngafidin, K. M. (2022). Scratch assisted physics learning with a STEM approach in the pandemic era to develop 21st century learning skills. *Jurnal Pendidikan IPA Indonesia, 11*(1), 185–194. https://doi.org/10.15294/jpii.v11i1.32607

Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: A meta-analysis study. *Frontiers in Psychology, 14,* 1202728. https://doi.org/10.3389/fpsyg.2023.1202728