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How to Improve Critical Thinking in Physics Learning? A Systematic Literature Review

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COME MIGLIORARE IL PENSIERO CRITICO NELL'APPRENDIMENTO DELLA FISICA? UNA REVISIONE SISTEMATICA DELLA LETTERATURA

Abstract

Critical thinking skills are essential skills needed in the 21st century. Critical thinking skills can be trained in students through student-centered learning. Through a literature review, this research aims to determine learning models that can improve critical thinking skills in physics. Data collection was based on Scopus and Google Scholar database sources. This type of document comes from journal articles with the keywords «critical thinking», «learning models», and «physics learning» from the years (2011-2021). The literature review used procedures adapted from PRISMA. Documents published are based on predetermined content analysis criteria, including year of publication, author, article source, learning model, physics material topic, research subject, education level, and assessment. Inquiry learning and the higher-order thinking laboratory (HOT Lab) dominate the learning models used to improve critical thinking skills. The critical skills indicators used vary. Indicators of critical thinking skills. Self-regulated learning is rarely *used in research instruments compared to other indicators of critical thinking skills. The instruments used are multiple-choice, essays, worksheets, and observation sheets. Research respondents at the university level are often used in studies of critical thinking skills. Fluid mechanics is a topic that is often used in research. This research contributes to improving students' critical thinking skills through various recommended learning models. Research findings show that student-centered learning models can improve critical thinking skills.*

Keywords: Critical thinking skills; Fluid mechanics; Guided inquiry; Learning models; Physics learning.

1. Introduction

Physics learning is essential in forming students' understanding of physics and the universe. In addition, critical thinking skills are a core competency needed to face the challenges of the 21st century (Tiruneh *et al.*, 2017; Duncan, 2020). Critical thinking skills enable individuals to carefully analyze, evaluate, and formulate thoughts and arguments, which is invaluable in understanding and handling the often complex and abstract concepts of physics. Critical thinking skills are needed in scientific inquiry (Furtak & Penuel, 2019). Research results recommend that critical thinking skills should be an explicit learning goal (Puig *et al.*, 2019). Critical thinking skills can be achieved if goal-oriented learning manipulates students' cognitive skills (Thompson, 2011). Critical thinking skills can be improved by using learning media and learning models (Weatherspoon *et al.*, 2015; Nugraha *et al.*, 2016; Hastuti *et al.*, 2018; Saputri *et al.*, 2019).

Experts define different critical thinking skills. Facione (2011) states that critical thinking skills help individuals overcome problems, understand information better, and make better decisions in various life contexts. Critical thinking skills also play an essential role in education, professional development, and informed and evidence-based decision-making. Facione (2011) critical thinking skills indicators consist of interpretation, analysis, evaluation, inference, and explanation. Binkley *et al.* (2012) stated that critical thinking skills are 21st-century skills that help achieve deep understanding, overcome complex problems, and develop broad thinking skills needed in various contexts. Binkley *et al.* (2012) stated that indicators of critical thinking skills consist of explaining, analyzing, interpreting, synthesizing, inference, and evaluating. Ennis (2016) states that critical thinking skills are valuable in problem-solving, decision-making, and deep understanding in various contexts. Meanwhile, Elder and Paul (2010) stated that critical thinking skills are the ability to actively analyze, formulate, identify assumptions, check data accuracy, and make decisions based on rational and logical evaluations.

Critical thinking skills in physics learning can be trained with scaffolding by providing real-world problems (ŽivkoviĿ, 2016) and strengthening students' conceptual understanding (Sin, 2014). Efforts can be made to train students' critical thinking skills with critical questions and habituation of thinking (Hastuti *et al.*, 2018; Ubaidillah *et al.*, 2022). Knowledge construction activities will be realized when students are given problems and try to find solutions, working collaboratively and participatively (Malik & Ubaidillah, 2020 and 2021). Critical thinking skills have clear relevance in the context of physics learning. Study results show that learning physics has improved students' critical thinking skills (Foote & Martino, 2018; Hadi *et al.*, 2018; Seranica *et al.*, 2018).

Previous literature review research examined five main topics related to practicing critical thinking skills, assessing critical thinking skills, strategies for teaching critical thinking skills, the taxonomy of critical thinking skills, and using technology for teaching (Alsaleh, 2020). Previous research discussed assessment, evaluation of critical thinking skills, learning strategies, and approaches to improve critical thinking skills in engineering students (Ahern *et al.*, 2019). Based on the literature review, studying critical thinking skills in physics learning is necessary. The systemic literature review explores physics researchers' and educators' efforts to develop students' critical thinking skills. The literature review focuses on learning models that can improve students' critical thinking skills, indicators and assessment of critical thinking skills, physics material taught, and education levels. This literature review research is essential to inform researchers, teachers, and education practitioners regarding learning models that can improve critical thinking skills in physics learning. The results of this literature review provide a solid basis for planning and developing a more effective curriculum in physics education that encourages strong critical thinking skills.

2. Methods

The research method uses a literature review with a modified procedure from a systematic review and a meta-analysis (PRISMA) (Page *et al.*, 2021). The procedure consists of identification, screening, eligibility, and inclusion. The research procedure is shown in *Figure 1*.

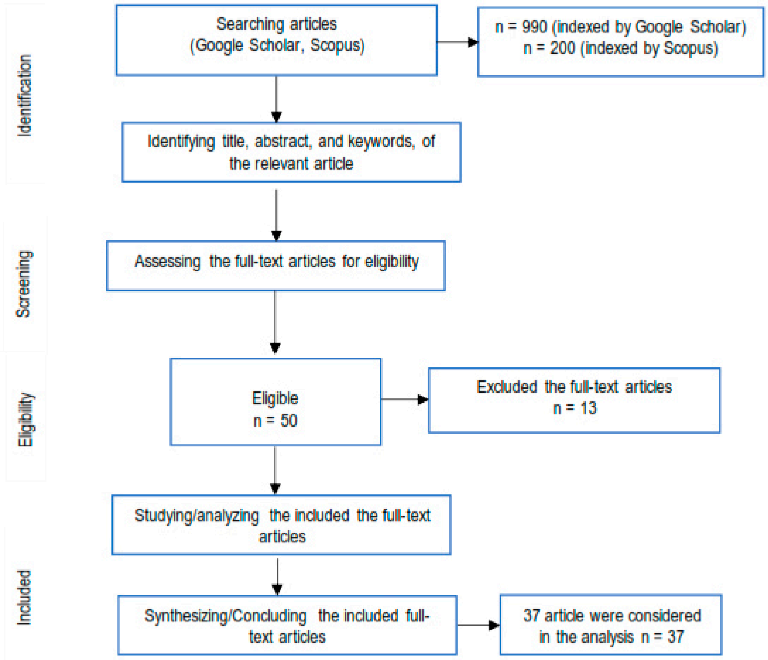

Figure 1. – Research procedure.

The research data uses a search from the Scopus journal indexing engine database and Google Scholar. Articles on the indexed database were published between 2011-2021. The keywords used to search the articles were «critical thinking», «models of teaching», and «learning physics». The articles used as data sources are articles published in journals, conference papers, and the English language. Articles from book chapters, book reviews, editorials, and commentaries are excluded from the analysis. Based on search data on the Google Scholar indexing engine, 990 articles were obtained, and 200 articles were obtained from Scopus. There are 50 eligible articles, but 13 are excluded from the analysis. The 13 articles excluded in this analysis were articles in languages other than English, used qualitative methods, and did not inform the physics material being taught. There are 37 articles analyzed in this systematic literature review. Data that meets the criteria is coded for further analysis. Data analysis was carried out based on the criteria of the learning model, indicators of critical thinking skills and types of instruments, the level of education used as a place of research, and the topic of physics materials.

3. Result

The article data is summarized in 4 categories related to learning models that can improve critical thinking skills, indicators of critical thinking skills and types of instruments, the level of education where the research was conducted, and the physics subject matter.

3.1. *Learning models that can improve critical thinking skills*

The learning model involves hands-on-science and mind-on-science activities. Critical thinking skills are enhanced through laboratory activities integrating discussion in solving problems. Learning with a hands-on science approach involves students through direct experience in experiments, trying, observing, and touching natural objects or laboratory equipment. Hands-on science is oriented towards practical experience and concrete exploration. Meanwhile, minds-on-science focuses more on understanding concepts and critical thinking. Students think, reflect, and consider science concepts more, often through discussion, analysis, and problem-solving. The learning model applied to improve critical thinking skills is shown in *Table 1*.

Learning models that can improve critical thinking skills (*Tab. 1*) are classified into 7. This classification is based on considering the characteristics of students' learning experiences, learning context, problem-solving, results orientation, and the technology involved in improving critical thinking skills. The classification of learning models is shown in *Table 2*.

The results of a literature review from various studies show that guided inquiry and HOT Laboratory are the learning models most widely used to improve students' critical thinking skills. The context of the studies included in the review developed comes from countries including the USA, Thailand, Indonesia, Belgium, and Turkey. A study was conducted in Turkey by Çorlu and Çorlu (2012), who examined scientific inquiry to improve critical thinking skills. Studies in Thailand were conducted by Onsee and Nuangchalerm (2019) and Soros *et al.* (2017), which apply Inquiry-Based STEM Learning and STEM Education. Hand *et al.* (2018) from the USA studied Argument-Based Inquiry with Science Writing Heuristics to improve critical thinking skills. Studies conducted in the USA were also carried out by Etkina & Planinšič (2015) and Mohottala (2016). The study was conducted in Belgium by Sermeus (2021), who applied the guided inquiry model to improve critical thinking skills. Studies from Indonesia dominate the results of a review conducted by Mutakinati *et al.* (2018), Suryani *et al.* (2018), Verawati *et al.* (2021), Wahyudi *et al.* (2019b), Malik and Ubaidillah (2020), and Lestari *et al.* (2021).

Table 1. – Learning models that can improve critical thinking skills.

No	Author	Model of teaching	Frequency
1	Nisa *et al.*, 2018; Syarkowi, 2018; Zain & Jumadi, 2018; Maknun, 2020; Medriati *et al.*, 2021; Ratna *et al.*, 2021; Sermeus *et al.*, 2021; Simatupang *et al.*, 2021	Guided inquiry	8
2	Malik *et al.*, 2017; Malik, Setiawan, Suhandi, Permanasari, Nasrudin *et al.*, 2018; Malik, Setiawan, Suhandi, Permanasari, Samsudin *et al.*, 2018; Setiawan *et al.*, 2018; Lisdiani *et al.*, 2019; Sutarno *et al.*, 2019; Putra *et al.*, 2021; Setya *et al.*, 2021	Higher-order thinking laboratory (HOT Lab)	8
3	Prayogi, 2018; Prayogi *et al.*, 2018; Prayogi *et al.*, 2019	Critical inquiry-based learning (CIBL)	3
4	Verawati *et al.*, 2019; Prayogi & Verawati, 2020	Conflict cognitive strategy in inquiry-based learning	2
5	Soros *et al.*, 2017	STEM education	1
6	Wartono *et al.*, 2018	Discovery inquiry	1
7	Malik & Ubaidillah, 2020	Multiple skill laboratory activity model (MSLAM)	1
8	Lestari *et al.*, 2021	Virtual classroom critical thinking (VC2T)	1
9	Risdianto *et al.*, 2020	Ethno science-based direct instruction learning	1
10	Wahyudi *et al.*, 2019a	Inquiry creative process (ICP)	1
11	Mohottala, 2016	Wikispaces (wikis) and Collaborative group problem-solving (CGPS)	1
12	Verawati *et al.*, 2021	Reflective inquiry learning (RIL)	1
13	Çorlu & Çorlu, 2012	Scientific inquiry	1
14	Etkina & Planinšič, 2015	Devising and testing multiple explanations of the same phenomenon	1
15	Wahyudi *et al.*, 2019b	Scientific creativity in inquiry learning	1
16	Hand *et al.*, 2018	Argument-based inquiry with science writing heuristic	1
17	Suryanti *et al.*, 2018	Inquiry learning	1
18	Mutakinati *et al.*, 2018	Project-based learning	1
19	Onsee & Nuangchalerm, 2019	Inquiry-based STEM learning	1
20	Ismail *et al.*, 2018	Mobile problem-based learning	1

Table 2. – Classification learning model.

No	Classification	Model of teaching
1	Inquiry-based learning	• Guided inquiry • Critical inquiry-based learning (CIBL) • Discovery inquiry • Scientific inquiry • Inquiry learning • Inquiry-based STEM learning • Argument-based inquiry with science writing heuristic (SWH)
2	Higher-order thinking and cognitive strategies	• Higher-order thinking laboratory (HOT Lab) • Multiple skill laboratory activity model (MSLAM) • Conflict cognitive strategy in inquiry-based learning • Devising and testing multiple explanations of the same phenomenon
3	STEM education	• STEM education
4	Technology-enhanced learning	• Virtual classroom critical thinking (VC2T) • Wikispaces (wikis) and collaborative group problem solving (CGPS) • Mobile problem-based learning
5	Reflective and creative learning	• Reflective inquiry learning (RIL) • Inquiry creative process (ICP)
6	Project-based learning	• Project-based learning
7	Ethnoscience and direct instruction	• Etnoscience-based direct instruction

3.2. *Aspects of indicators and types of critical thinking skills instruments*

The article review results show that the references to critical thinking skills that the authors refer to in their research vary greatly. Binkley's critical thinking ability is most widely used as an indicator in the papers studied. There are six indicators of Binkley's critical thinking skills found in eight papers. Facione's critical thinking ability is also found in many papers, but indicators of Facione's critical thinking ability vary significantly in several papers, likewise with Ennis' critical thinking abilities. The paper review results based on critical thinking ability indicators are presented in *Table 3*.

Table 3. – Aspects of critical thinking indicators used in research.

No	Reference	Indicator of critical thinking	Frequency
1	Binkley *et al.*, 2012	Explain, analyze, interpreting, synthesizing, inference and evaluation	8
2	Facione, 1990	Analysis, inference, evaluation and decision-making	6
3	Facione, 1990	Interpretation, analysis, evaluation, inference, explanation and self-regulation	5
4	Facione, 1990	Interpretation, evaluate arguments, inference and explanation	2
5	Facione, 2011	Interpretation, analysis, evaluation, inference and explanation	1
6	Ennis, 1985	Providing simple explanations, building basic skills, making conclusions, making further explanations, and arranging strategies and tactics	4
7	Ennis, 2016	Basic clarification, the bases for a decision and inference skills	1
8	Ennis, 1995	The skills to formulate the problem, give the argument, induction, evaluating and to decide a course of action	1
9	Ennis, Millman, & Tomko, 2005	Deduction, induction, assumption, observation and credibility	1
10	Ennis 2011; Facione, 2011; Lai 2011	Focus on the question, analyze arguments, decide action, observing induces data, further explanation	1
11	Paul-Elder, 2010	Critical thinking based on purpose and question, selection of information, assumption, point of view the solution, implication and consequences	1
12	Dressel & Mayhew, 1954	Ability to clarify the problem situation, gather information, accept the agreement, set up the hypothesis and reasonably conclude	1
13	Etkina & Planinšič, 2015	Asking question and defining problem, analyzing, interpreting data, prediction, explanation, evaluation assumption	1
14	Halpern, 2010	Hypothesis testing, verbal reasoning, argument analysis, likelihood and uncertainty analysis, problem-solving and decision-making	1
15	No mention of source	Only mentions critical thinking variables without indicators	3

The critical thinking skills indicator from Binkley *et al.* (2012) was the most widely referenced in the papers reviewed with eight articles. According to Facione, critical thinking skills referred to in studies vary greatly. Likewise, with Ennis' indicators of critical thinking skills. Meanwhile, thinking indicators from Paul-Elder (2010), Halpern (2010), Etkina and Planinšič (2015), Ennis, Millman and Tomko (2005), Dressel and Mayhew (1954) are rarely referred to in studies. The remaining three studies did not mention the reference source for critical thinking skills in the study.

Types of critical thinking skills instruments from the articles reviewed using various instruments. Critical thinking skills instrument types are multiple-choice tests (Hand *et al.*, 2018; Maknun, 2020), multiple-choice by Halpern Critical Thinking Assessment (HCTA) (Sermeus *et al.*, 2021), worksheets and observation sheets (Mutakinati *et al.*, 2018), Weir Critical Thinking Essay Test adapted from Ennis (Wahyudi *et al.*, 2019a), and Essay test (Wartono *et al.*, 2018; Malik & Ubaidillah, 2020; Lestari *et al.*, 2021; Verawati *et al.*, 2021). HCTA is a validated domain of general critical thinking skills that measures critical thinking skills in everyday situations (Marin & Halpern, 2011; Sermeus *et al.*, 2021). The HTCA skills test type selection is based on critical thinking skills, which are commonly mentioned in various definitions of critical thinking skills, and it includes adequate and well-structured items that appear to measure each critical thinking skill identified (Tiruneh *et al.*, 2017).

3.3. *Classification based on level of education*

The educational levels that are the object of research on improving critical thinking include higher education, senior high school, junior high school and primary school. Higher education is in first place with 17 papers. Senior high school took second place with 16 papers. While junior high school and primary school with two papers. The classification of critical thinking skills research based on education level is presented in *Table 4*.

Table 4. – Classification based on level of education.

No	Level of education	Frequency
1	Higher education	17
2	Senior high school	16
3	Junior high school	2
4	Primary school	2

3.4. *Classification based on physics subject matter*

The results of mapping articles related to physics subject matter taught to improve critical thinking skills are very diverse. Each material topic has unique characteristics that can develop students' critical thinking. Fluid mechanics is the material most studied in research on improving critical thinking skills. The elasticity of materials, sound and waves, optics, light, measurements, states of matter, scientific terms in physics, photoelectric effect, electricity and magnetism, electric current, and elasticity are the least used materials. The classification based on physics subject matter is shown in *Table 5*.

Table 5. – Classification based on physics subject matter.

No	Subject matter	Frequency
1	Fluid mechanics	7
2	Static fluid	4
3	Electricity	4
4	Work and energy	3
5	Temperature and heat	3
6	Force and laws of motion	2
7	Mechanics	2
8	Magnetic field	2
9	Elasticity	1
10	Sound and wave	1
11	Optics	1
12	Light	1
13	Measurement	1
14	Substance form	1
15	Physics scientific terms	1
16	Photoelectric effect	1
17	Electricity and magnetism	1
18	Electric current and elasticity	1

4. Discussion

Learning models oriented towards laboratory activities have significantly grown in Indonesia in recent years. Improving students' critical thinking skills is one of the learning outcomes targets that must be achieved. This was motivated by the Indonesian government's dissatisfaction with the results of PISA and TIMSS. The low ability to solve high-level thinking questions has encouraged the birth of curriculum policies oriented toward 21st-century skills (Verawati *et al.*, 2019). Physics educators are encouraged to apply learning that trains thinking skills in learning (Afriana *et al.*, 2016; Verawati *et al.*, 2021).

The information obtained from *Table 1* shows that learning models that can improve critical thinking skills can be mapped into several models. Categorization is based on the characteristics that characterize each learning model. The categorization of learning models is classified into inquiry-based learning, higher-order thinking and cognitive strategies, STEM education, technology-enhanced learning, reflective and creative learning, project-based learning, and ethnoscience and direct instruction. Characteristics of learning models oriented towards inquiry-based learning, namely, guided inquiry, critical inquiry-based learning (CIBL), discovery inquiry, scientific inquiry, argument-based inquiry with science writing heuristic, inquiry learning, and inquiry-based STEM learning. The characteristics of learning models that are oriented towards higher-order thinking and cognitive strategies include; higher-order thinking laboratory (HOT Lab), conflict cognitive strategy in inquiry-based learning, scientific creativity in inquiry learning, devising and testing multiple explanations of the same phenomenon. The category of learning models oriented towards technology-enhanced learning is the virtual classroom critical thinking (VC2T), Wikispaces (wikis) and collaborative group problem-solving (CGPS) model, mobile problem-based learning. Characteristics of learning models that are oriented towards reflective and creative learning, namely the reflective-inquiry learning (RIL), inquiry-creative process (ICP) models.

Guided inquiry trains students in inquiry skills, collect data, processes data, and builds conclusions to answer teacher questions (Maknun, 2020). Guided inquiry refers to Spiro and Knisely has five stages; observing and generalizing questions, making a hypothesis, designing the experiment, Conducting an experiment to obtain information, analyzing data, and experiment reports (Maknun, 2020; Medriati *et al.*, 2021). Guided inquiry in the implementation of physics learning is carried out based on blended learning (Zain & Jumadi, 2018), reading assignments in guided inquiry learning (Syarkowi, 2018), guided inquiry learning assisted by computer simulations (Ratna *et al.*, 2021), and guided inquiry model only (Nisa *et al.*, 2018; Maknun, 2020; Medriati *et al.*, 2021; Sermeus *et al.*, 2021; Simatupang *et al.*, 2021). Guided inquiry-based on blended learning in physics is made by online and face-to-face learning. The orientation and exploration stages are carried out online. The stages of data collection, testing the hypothesis, and communication are face-to-face learning (Zain & Jumadi, 2018). The improvement of students' critical thinking skills through the guided inquiry model is because students are allowed to construct concepts by presenting problems, formulating hypotheses independently, collecting data, analyzing, and making conclusions (Maknun, 2020). Problem-solving and habituation of thinking encourage students to explore so that learning is more meaningful (Simatupang *et al.*, 2021). Through experiments such as scientific exploration and explanation, guided inquiry activities can improve critical thinking skills (Syarkowi, 2018).

The critical inquiry-based learning (CIBL) model was developed based on the inquiry process in learning that accommodates aspects of students' prior knowledge, motivation, and critical thinking skills. The CIBL model has six stages: orientation, exploration, analysis, inference, evaluation, and reflection (Prayogi, 2018). The worksheet is designed in the CIBL model as a guide in practicing the critical thinking skills of prospective physics teachers. Each phase of the CIBL model can train the critical thinking skills of prospective physics teacher students. Student-teacher candidates are given anomaly data on problem orientation activities. Providing anomaly data (contradictive information) can improve critical thinking skills (Prayogi *et al.*, 2019). At the orientation stage, prospective physics teacher students carry out explanatory activities to develop critical thinking skills. Exploration activities involve students conducting investigations that practice scientific reasoning and critical thinking skills (Prayogi *et al.*, 2018). After the prospective physics teacher, students conduct exploration, and they carry out the process of analysis, inference, and evaluation. Analysis, inference, and evaluation are the main indicators of critical thinking. Students connect previous knowledge experiences with new knowledge in inquiry activities. This can lead to students' cognitive conflicts that foster critical thinking skills. Creating a student-centered learning environment that involves dialogue where students engage in critical thinking is more reflective of the epistemic practice of scientists (Hand *et al.*, 2018).

The higher-order thinking laboratory (HOT Lab) was developed from a problem-solving laboratory and creative problem-solving model (Malik, Setiawan, Suhandi, Permanasari, Samsudin *et al.*, 2018; Malik *et al.*, 2019). The HOT Lab has 11 stages: real-world problems, determining and evaluating ideas, asking experiment questions, providing materials and equipment, predicting, applying question methods, exploring, measuring, analyzing, concluding, and presenting (Malik, Setiawan, Suhandi, & Permanasari, 2018). The HOT Lab model consists of five general processes; understand the challenges are given, produce ideas, prepare practical activities, carry out practical activities, and communicate and evaluate the results of activities. The HOT Lab model can train convergent and divergent thinking skills (Malik, Setiawan, Suhandi, & Permanasari, 2018). In stages of real-world problems, students are given real problems related to the material. Students are trained in critical thinking skills when solving real problems.

Conflict-cognitive strategy in the inquiry-based learning model can improve students' critical thinking skills (Verawati *et al.*, 2019; Prayogi & Verawati, 2020). Cognitive conflict occurs when a student's experience is inconsistent with new knowledge. Conflicts in the cognitive structure are a significant part of inquiry (Prayogi, 2018). Conflict-cognitive strategies in inquiry-based learning serve as a catalyst. Conflict-cognitive strategies develop cognitive aspects in the learning process to train students' critical thinking skills. Cognitive-conflict strategies make learning meaningful. The cognitive-conflict strategy intervention in the inquiry-based learning model in this study is in 3 learning sequences, namely setting a set and conveying learning objectives, presenting or demonstrating contradictory information (anomaly data) to generate motivation in learning, and finally presenting an advance organizer as a follow-up further from the data anomalies presented.

Research findings show that learning that involves collaboration and interaction of constructivist learning environments and integrative pedagogy has a positive impact on critical thinking skills, creative thinking, problem-solving, decision-making skills, student communication skills (Virtanen & Tynjälä, 2019) and concept understanding (Adolphus & Omeodu, 2016). Students actively construct knowledge through observation and experience (Sawitre & Pipitgool *et al.*, 2021). Critical thinking skills can be improved through investigative and discussion activities (Alsarayreh, 2021). Arguments in the discussion can help students build knowledge (Akhdinirwanto *et al.*, 2020). Efforts to develop critical thinking skills in learning are carried out by transferring knowledge, stimulating student cognition, critical understanding of the material, and reflective learning teaching models to improve critical thinking skills include explicit learning critical thinking skills, developing a disposition to think hard, learning direct learning activities to increase the possibility of trans contextual transfer (structure training), and explicit and open metacognitive monitoring (Halpern, 2013).

The study of STEM teaching and learning has become trendy in recent years. Physics learning that integrates with STEM has the opportunity to improve 21st-century skills and promote STEM literacy for the global community (Schmidt & Fulton, 2016). STEM education can improve critical thinking and problem-solving skills (Soros *et al.*, 2017; Onsee & Nuangchalerm, 2019). Most students believe in STEM in various countries to guarantee future career success (Tseng *et al.*, 2013). The rapid development of STEM education can provide opportunities for researchers to study various aspects such as curriculum, policy, teaching, and teacher education.

Technology currently plays an essential role in learning. Integrating technology with learning models has an impact on improving critical thinking skills. The use of mobile learning technology, virtual classrooms, and Wikispaces in physics learning has proven to improve students' problem-solving, thinking, and collaborative abilities (Mohottala, 2016; Ismail *et al.*, 2018). Physics learning that integrates with local culture is considered an effort to bring the science context closer to students. Indigenous knowledge of the community as a context for learning physics positively impacts students' science explanation abilities in the classroom. Students' direct experiences in daily life related to physics contribute to the construct of knowledge. Study results show that learning that integrates ethnoscience can improve students' critical thinking skills (Risdianto *et al.*, 2020).

Critical thinking is a reflective judgment about what to believe or do in a particular context (Facione *et al.*, 2017). Critical thinking is analyzing and assessing thinking to improve it (Elder & Paul, 2010). The critical thinking approach in learning contributes to the formation of new knowledge (Howlett *et al.*, 2016). Facione's critical thinking skills indicators are interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 1990). Self-regulated learning has sub-indicators of self-examination and self-correction. Self-regulated learning is an indicator of critical thinking skills that are rarely measured in research based on paper reviews compared to other indicators from Facione. Self-regulated learning is a level that involves other critical thinking skills indicators such as interpretation and inference. Self-regulated learning has different characteristics from other thinking skills indicators. Self-regulated learning is a metacognitive aspect that is difficult to access using multiple-choice test questions and descriptions (Facione, 1990). Self-regulated learning can be measured using a questionnaire instrument distributed through surveys (Alpaslan *et al.*, 2016; Li *et al.*, 2018).

Not all critical thinking indicators are used in the research as a whole. Critical thinking skills from Facione include analysis, inference, evaluation, and decision-making (Wahyudi *et al.*, 2019a and 2019b; Verawati *et al.*, 2021). The indicators of critical thinking skills used in the paper are taken from Facione, namely Interpretation, analysis, evaluation, inference, and explanation (Lestari *et al.*, 2021). Decision-making skills combine intuitive and reflective (Facione, 2011). There are six levels of critical thinking in the research: master thinker, advanced thinker, practicing thinker, beginning thinker, challenged thinker, and unreflective thinker (Mutakinati *et al.*, 2018; Paul & Elder, 2020).

Research on improving critical thinking skills is mainly done in higher education. Critical thinking skills are essential competencies highly emphasized in higher education (Halpern, 2013). Research on prospective physics teacher-students is carried out in various universities (Etkina & Planinšič, 2015; Syarkowi, 2018; Sutarno *et al.*, 2019; Malik & Ubaidillah, 2020; Verawati *et al.*, 2021). Research related to improving critical thinking was carried out at the high school level. It is improving critical thinking skills by applying the HOT Lab with 72 high school students as the subject (Lisdiani *et al.*, 2019). Research with the subject of high school students is one class as the control class and one class as the experimental class (Medriati *et al.*, 2021).

College graduates need critical thinking skills. Critical thinking skills are essential in learning and facing an uncertain future (Halpern, 2013). Students with superior critical thinking skills have better job prospects (Freudenberg & Brimble, 2009). College students need to be equipped with critical thinking skills. Learning in higher education is designed to develop problem-solving skills and is oriented toward critical thinking skills (Ennis, 2016). Critical thinking skills for prospective physics teacher students are essential in understanding physical phenomena (Sin, 2014). Physics learning at the beginning of the semester in college is focused on teaching the concepts and principles of physics. Critical thinking skills are inadequate if applied too early in lectures (Howlett *et al.*, 2016). Critical thinking skills, problem-solving, and communication need to be integrated into physics learning (Jones, 2009).

The age of the individual contributes to the development of critical thinking (Hyytinen, 2015). Critical thinking skills occur when students carry out the task of building knowledge and skills in complex situations (Hyytinen *et al.*, 2019). Student-teacher candidates have the characteristics of formal operational thinking. Students can think abstractly and complexly. Solving logical operational problems shows critical thinking and scientific reasoning (Domingo *et al.*, 2021).

The topics of physics material used in research vary widely. The choice of physics material has different characteristics. More than one topic of physics material is used in one research paper, such as electricity and magnetism (Sermeus *et al.*, 2021), electric current and elasticity (Malik & Ubaidillah, 2020), sound and waves (Risdianto *et al.*, 2020), temperature and heat (Simatupang *et al.*, 2021), and work and energy (Onsee & Nuangchalerm, 2019).

Fluid mechanics material is very close to students' daily lives. Presentation of problems related to the phenomenon of fluid mechanics is the trigger for cognitive conflict. Students often face problems related to fluid mechanics in their daily life. When students are faced with new problems related to fluid mechanics and do not accord to previous experience, there is a change in cognitive structure. When fluid mechanics is taught in physics, it can cause cognitive conflicts that foster critical thinking skills (Verawati *et al.*, 2019).

Previous research has shown that electrical material is a material that students often have misconceptions (Masson *et al.*, 2014; Memiş & Seven, 2015). Other studies have shown that students have misconceptions about various physics materials such as electric circuits (Baser, 2006; Peşman & Eryilmaz, 2010), classical mechanics (Hasan *et al.*, 1999), Newton's laws (Kaniawati *et al.*, 2019), and electric circuits (Planinic *et al.*, 2006), fluid mechanics (Huilier, 2019), thermodynamics (Foroushani, 2019), quantum mechanics (Singh *et al.*, 2006), waves (Hasan *et al.*, 1999; Caleon & Subramaniam, 2010), heat transfer and kinetic theory (Pathare & Pradhan, 2010), and optical geometry (Kaltakci-Gurel *et al.*, 2017). Cognitive processes, reasoning skills, and reflective thinking needed in critical thinking are solutions to rejecting misconceptions (Bensley *et al.*, 2014). Critical thinking is a helpful way to overcome misconceptions (Dellantonio & Pastore, 2021). Giving examples and analogies can correct the misconceptions about physics (Brown, 1992).

5. Conclusion

This review has provided information regarding efforts to improve students' critical thinking skills in physics learning in various countries. This paper focuses on revealing the use of learning models, critical thinking skills instruments, education levels, and physics materials by practitioners in improving critical thinking skills. Improving critical thinking skills in physics learning can be done by implementing learning that involves students in problem-solving through laboratories, presenting problems that stimulate cognitive conflict, real-world problems, investigations, and projects. Critical thinking skills can be trained at all levels of education. The results of the research provide information to teachers regarding the application of learning models that can improve students' critical thinking abilities. Future researchers can conduct literature studies on the success of improving critical thinking across countries based on cultural and contextual differences that can influence the success of different strategies, examine the impact of teacher professional development on improving students' critical thinking skills, and develop new critical thinking instruments.

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Riassunto

Le abilità di pensiero critico sono competenze essenziali necessarie nel 21° secolo. Le abilità di pensiero critico possono essere addestrate negli studenti attraverso l'apprendimento centrato sullo studente. Attraverso una revisione della letteratura, questa ricerca mira a determinare modelli di apprendimento che possano migliorare le abilità di pensiero critico in fisica. La raccolta dei dati si è basata su fonti di database Scopus e Google Scholar. Questo tipo di documento proviene da articoli di riviste con le parole chiave «pensiero critico», «modelli di apprendimento» e «apprendimento della fisica» degli anni (2011-2021). La revisione della letteratura ha utilizzato procedure adattate da PRISMA. I documenti pubblicati si basano su criteri di analisi del contenuto predeterminati, tra cui anno di pubblicazione, autore, fonte dell'articolo, modello di apprendimento, materia di fisica, argomenti di ricerca, livelli di istruzione e valutazioni. L'apprendimento basato sull'indagine e il laboratorio di pensiero di ordine superiore (HOT Lab) dominano i modelli di apprendimento utilizzati per migliorare le abilità di pensiero critico. Gli indicatori delle competenze critiche utilizzati variano. Indicatori di abilità di pensiero critico: l'apprendimento autoregolato è raramente utilizzato negli strumenti di ricerca rispetto ad altri indicatori di abilità di pensiero critico. Gli strumenti utilizzati sono la scelta multipla, saggi, fogli di lavoro e schede di osservazione. Gli intervistati della ricerca a livello universitario sono spesso utilizzati negli studi sulle abilità di pensiero critico. La meccanica dei fluidi è un argomento che viene spesso utilizzato nella ricerca. Questa ricerca contribuisce a migliorare le abilità di pensiero critico degli studenti attraverso vari modelli di apprendimento consigliati. I risultati della ricerca mostrano che i modelli di apprendimento incentrati sullo studente possono migliorare le abilità di pensiero critico.

Parole chiave: Abilità di pensiero critico; Apprendimento della fisica; Indagine guidata; Meccanica dei fluidi; Modelli di apprendimento.

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