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The Effectiveness of Problem-Based Learning Based on Socio-Scientific Issues on Students' Critical Thinking: A Systematic Literature Review

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ABSTRACT

Purpose– This study aims to analyze the impact of learning using the Socio-Scientific Issues (SSI)-based Problem-Based Learning (PBL) model on students' critical thinking skills in biology. Although various studies have examined PBL and SSI separately, there has not yet been a comprehensive study that summarizes the combined effectiveness of the PBL-SSI model and maps the development of research in this field. This study fills this gap through a systematic analysis of the latest empirical findings.

Methodology – This study employed the Systematic Literature Review (SLR) method, adhering to the PRISMA guidelines. The articles analyzed were 35 indexed articles published between 2019 and 2024 with the keywords 'Problem-Based Learning (PBL)', 'Socio-Scientific Issues (SSI)', and 'Critical Thinking'. VOSviewer was used to map related keywords, followed by qualitative analysis.

Findings – The study's results indicate that approximately 80% of studies report a significant improvement in students' critical thinking skills following the application of the PBL-SSI model. Environmental topics such as pollution, climate change, and renewable energy are the most dominant themes due to their relevance and authenticity. Bibliometric analysis also confirms a strong correlation between the keywords "PBL," "SSI," and "Critical Thinking," indicating growing scientific interest in this integrated learning model. The correlation between PBL and SSI is more pronounced than the application of either one alone, as it enables students to solve real-world problems actively, considering both scientific and social aspects.

Contribution –These findings have practical implications for educators, including the development of authentic teaching materials and the integration of fundamental social and environmental issues into the learning process.

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INTRODUCTION

The 21st century has been marked by the Industrial Revolution 5.0, which promotes openness and globalization. These developments require humans to undergo significant transformation, particularly by enhancing the quality of their human resources, in order to compete globally. One strategic effort that can be made is through improving the quality of education at all levels. In this context, 21st-century learning emphasizes the mastery of various competencies, including creativity, critical thinking skills, cooperation, problem-solving, as well as communication, social, and character skills (Jufriadi et al., 2022).

These skills align with the characteristics of 21st-century skills developed by the Partnership for 21st Century Skills, including Learning and Innovation Skills (4C), Information, Media, and Technology Skills, as well as Life and Career Skills (Muladi et al., 2022). This means that 21st-century learning is no longer limited to traditional literacy skills, such as reading and memorization, but requires students to think critically, creatively, and solve problems in everyday life.

However, students' critical thinking skills in Indonesia are still relatively low. This is clearly illustrated by the results of the 2022 PISA assessment, in which Indonesia's science literacy score averaged 366 and ranked 70th out of 81 countries (OECD, 2023). The science literacy tested in PISA covers three main aspects, namely: (1) scientific explanation of a phenomenon, (2) assessment and design of scientific research, and (3) interpretation of scientific data and evidence. These three aspects require high-level thinking skills, particularly critical thinking. Thus, low PISA scores suggest that students in Indonesia have not been able to develop their critical thinking skills optimally. Therefore, learning innovations are needed that can stimulate higher-order thinking skills through authentic and meaningful contexts.

In line with today's young generation, which is required to possess 4C skills, namely critical thinking, communication, collaboration, and creativity. The current learning process should be more dynamic and not rely solely on teachers as the center of learning, as learning is tailored to student preferences and incorporates various learning styles, including auditory, visual, and kinesthetic, in balanced proportions. Facione identifies several aspects of critical thinking skills, including interpreting, analyzing, evaluating, concluding, explaining, and self-regulating (Facione, 2015). Critical thinking skills need to be instilled from an early age. In a global work environment, critical thinking skills are crucial for making informed decisions that have a significant impact on organizations or companies.

The solution to meeting the demands of the 21st century and addressing the low level of critical thinking among students is to provide new ways of learning, one of which is the incorporation of the Problem-Based Learning (PBL) model. PBL is a learning model that helps students acquire the skills necessary in the era of globalization, as it utilizes real-world problems as a context for students to develop critical thinking, problem-solving, and essential concepts from the subject matter (Burhana et al., 2021). Problem-based learning can encourage students to work together in teams or independently to solve problems. Through problem investigation and analysis activities, PBL creates a learning environment that encourages students to build knowledge independently and collaboratively, thereby contributing to improved learning outcomes, especially in science subjects (Aprina et al., 2024).

The PBL learning model can be combined with an approach that presents authentic issues that give rise to conceptual conflicts and require discussion in finding solutions, such as Socio-Scientific Issues (SSI). Socio-Scientific Issues (SSI) are social problems related to science that are complex in nature and have various possible answers (Shoba et al., 2023). SSI provides an authentic context that encourages students to analyze real issues and make decisions based on scientific evidence. This approach plays a crucial role in science learning, as it fosters science literacy by connecting science content to relevant social contexts (Hidayat & Hidayati, 2024). SSI aims to teach students not only about content knowledge but also about the nature of science, offering students the opportunity to practice argumentation and decision-making (Schenk et al., 2021).

The integration of PBL and SSI is considered to have great potential in improving critical thinking skills, as both emphasize real-world problem solving and evidence-based argumentation. However, the application of these two approaches in the context of biology education in Indonesia is still minimal and has not been systematically studied. Most previous studies have focused solely on the implementation of PBL or SSI separately, thereby failing to provide a comprehensive picture of the effectiveness of integrating the two approaches in developing critical thinking skills. Therefore, this study is important to fill this gap by systematically reviewing various research results that discuss the integration of PBL–SSI and its impact on students' critical thinking skills. The limitations of studies examining PBL and SSI simultaneously can be understood in light of the focus of previous research. PBL studies generally emphasize the process of investigation and problem-solving, while SSI studies highlight the analysis of science-based social issues. The integration of the two requires a learning design that links real-world problems to social contexts and assessments that weigh critical thinking and scientific argumentation. Due to its more complex demands compared to single applications, research combining PBL–SSI in an effort to develop critical thinking skills is still relatively limited to the context of biology.

Biology is the science that studies living things, phenomena, and life processes that interact with society. Biology learning is a learning process that provides students with direct and meaningful experiences to help them understand their environment (Banila et al., 2021). Biology learning encompasses concepts, phenomena, and life processes that exist around us, which are closely related to daily activities, whether in the context of humans, animals, plants, microorganisms, or their environments.

SSI and PBL are closely related in the biology learning process because both connect scientific concepts with real-world challenges. SSI supports students in understanding social issues such as pollution and vaccination, while PBL trains them to find solutions through scientific research. When the two are combined, students will be encouraged to think critically, care about the environment, and connect biology with their daily activities. In line with this, this study focuses on examining the effectiveness of SSI-based PBL integration in improving critical thinking skills in biology learning through a systematic literature review.

METHODOLOGY

Research Design

This study employs a Systematic Literature Review (SLR) to examine the application of the Socio-Scientific Issues (SSI)-based Problem-Based Learning (PBL) model in enhancing critical thinking skills in environmental pollution education in Indonesia. The search process was divided into several stages, including identification, screening, eligibility, and inclusion. These stages were in accordance with the guidelines listed in PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). PRISMA is a set of evidence-based standards that aim to guide authors in compiling reports on various systematic reviews and meta-analyses that assess effectiveness. PRISMA emphasizes ways in which authors can ensure that the reports they produce are transparent and comprehensive in relation to the type of research conducted (Sastypratiwi & Nyoto, 2020).

Data Collection

The literature search was conducted through several databases, including Google Scholar, DOAJ, Portal Garuda/SINTA, and Scopus, for the period 2020-2025. The keywords used included "problem-based learning," "PBL," "socio-scientific issues," "SSI," "critical thinking," "biology education," and "science education." Keyword combinations were applied using Boolean operators, for example: ("problem-based learning" OR "PBL") AND ("socio-scientific issue" OR 'SSI') AND ("critical thinking") AND (biology OR science).

Inclusion criteria were specifically established to ensure that articles were relevant to the research objectives, namely: 1) Articles published between 2020 and 2025. 2) Using experimental, quasi-experimental, or qualitative research designs. 3) Research subjects were junior high school, high school, or prospective

biology/science teacher students. 4) The research discusses the implementation of PBL, SSI, or the integration of PBL–SSI in biology or science learning. 5) The article presents empirical data in the form of critical thinking test results, observations, interviews, or learning document analysis. 6) The article is published in a peer-reviewed journal in Indonesian or English. The exclusion criteria include: 1) Articles that do not present empirical data or do not include critical thinking measurement results. 2) Research conducted outside the context of biology/science learning. 3) Articles in the form of proceedings, project reports, theses, dissertations, or non-peer-reviewed preprints. 4) Duplicate articles from different databases.

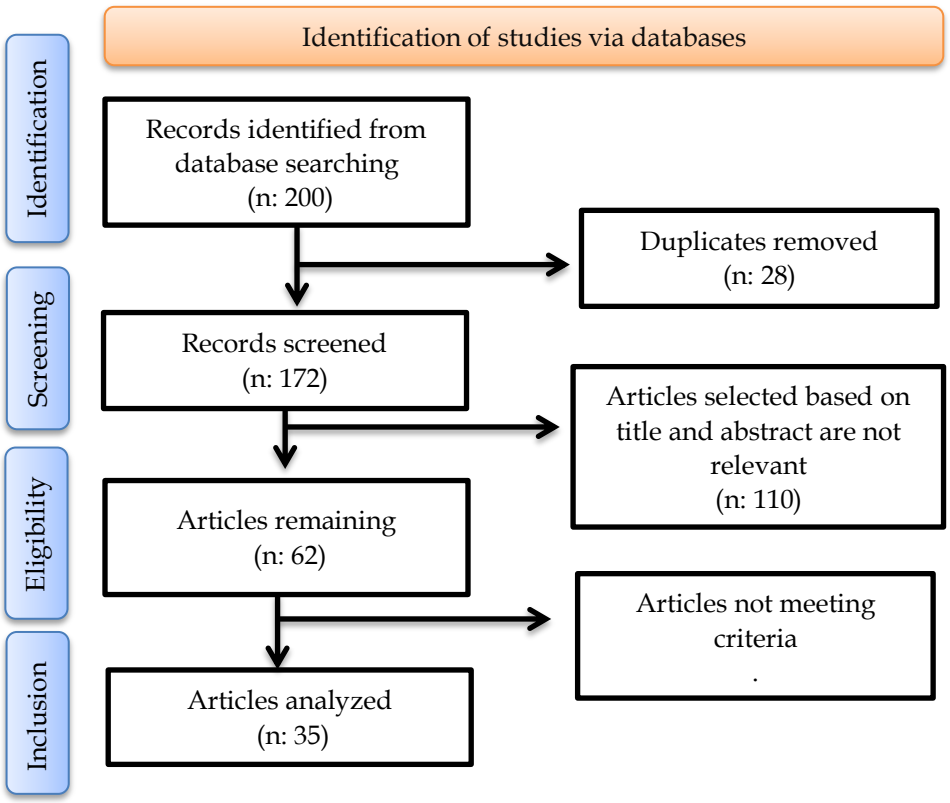

Figure 1. Literature search procedure according to PRISMA guidelines

Relevance assessment was conducted by examining the title, abstract, and research objectives to ensure that the article discussed PBL, SSI, or the integration of both in science/biology learning and measured critical thinking skills. Research quality assessment was conducted by reviewing the suitability of the research design (experimental, quasi-experimental, or qualitative), the clarity of data collection procedures, the reporting of instruments that measure critical thinking, the accuracy of data analysis, and the status of peer-reviewed journals. Articles were categorized as having empirical data if they presented data collection results through research instruments (e.g., critical thinking tests, observations, or interviews) and reported quantitative or qualitative data. Articles that did not present empirical data were excluded from the analysis.

From the initial search results, 200 articles relevant to the research variables were found. After screening based on the inclusion and exclusion criteria, 35 articles were identified as eligible for further analysis. These articles were then evaluated based on methodological quality, clarity of research procedures, reporting of critical thinking instruments, accuracy of data analysis, and validity of results. The instruments used in this study were designed to determine the criteria for selecting articles to be reviewed, specifically the inclusion and exclusion criteria. Basic data analysis was performed using VOSviewer software to identify research deficiencies through network visualization. Next, relevant articles were selected based on their relevance to the research theme, particularly in terms of their titles, abstracts, and the quality of the research procedures and techniques applied. The data obtained will be analyzed in a structured manner, and the results of the analysis visualization will be interpreted to assess the effectiveness of various assessment methods. A literature review is a comprehensive study of articles, books, and other sources related to a particular field of

research or theory, providing a descriptive summary and critical evaluation of the work (Ramdhani et al., 2014). The steps in the article selection process yielded the following results.

The identification stage of this study resulted in the discovery of 200 articles from various databases, identified through the use of relevant keywords. This was followed by a screening stage to remove duplicate articles, leaving 172 unique articles. These articles were then reselected at the eligibility stage by reviewing the titles and abstracts. A total of 110 articles were deemed irrelevant to the study's focus, resulting in 62 articles remaining. Another selection was made based on inclusion criteria in accordance with the variables studied, such as direct relevance to Problem-Based Learning (PBL), Socio-Scientific Issues (SSI), and the measurement of critical thinking skills, resulting in the elimination of 27 articles that did not meet the criteria. Finally, 35 articles were selected as suitable for further analysis in this study to obtain a comprehensive understanding of the effectiveness of the SSI-based PBL model in enhancing students' critical thinking skills in biology learning.

Data Analysis

The data analysis technique used in this study is qualitative analysis. Qualitative data are obtained by studying topics related to the research and collecting or compiling data from various reliable existing sources of literature. The researcher compiled and collected data from studies relevant to the research being conducted, as well as from various articles that support the research problem, specifically the relevance of the PBL model and the SSI approach to improving critical thinking skills from 2020 to 2025.

FINDINGS

Based on the results of a search of 35 of the 200 national and international articles that were identified, the articles were then reviewed against predetermined criteria, and the selected journals were analyzed by examining each section thoroughly. The selection process was conducted by referring to the established inclusion and exclusion criteria. In this study, articles related to Problem-Based Learning, Socio-Scientific Issues, and Critical Thinking were found.

Table 1. List of Articles Reviewed in the SLR Study

No.	Author	Publisher	Article Title
1.	(Masruro et al., 2021)	International Journal of Recent Educational Research (IJORER)	Profile of Problem-Based Learning to Improve Students' Critical Thinking Skills
2.	(Wahdaniyah & Agustini, 2023)	International Journal of Recent Educational Research (IJORER)	Analysis of the Effectiveness of PBL-STEM to Improve Students' Critical Thinking Skills
3.	(Dusturi et al., 2024)	Jurnal Penelitian Pendidikan IPA (JPPIPA)	Socio-Scientific Issues (SSI) Approach Implementation in Science Learning to Improve Students' Critical Thinking Skills: Systematic Literature Review
4.	(Putri et al, 2022)	International Journal of Advanced Research (IJAR)	Development of a Problem-Based Learning Model Based on Socio-Scientific Issues to Improve Student Critical Thinking Skills on Materials For Environmental Change and Conservation in Senior High School
5.	(Fita et al., 2021)	Studies in Learning and Teaching	The Effectiveness of Problem-Based Learning (PBL) Based Socio-scientific Issue (SSI) to Improve Critical Thinking Skills
6.	(Izzah et al., 2022)	Journal of Innovative Science Education (JISE)	The Effectiveness of Socio-scientific Issues-Based Learning and Digital Literacy to Build Critical Thinking Skills for Students of Senior High School
7.	(Aisy & Trisnowati, 2024)	Jurnal Inovasi Pendidikan IPA (JIPI)	The Effect of the Problem-Based Learning (PBL) Model in The Effect of the Problem-Based Learning (PBL) Model in the Context of Socio-Scientific Issues (SSI) on Critical

No.	Author	Publisher	Article Title
			Thinking Ability on Digestive System Material
8.	(Hernández-Ramos et al., 2021)	Multidisciplinary Digital Publishing Institute (MDPI)	The Effects of Using Socio-Scientific Issues and Technology in Problem-Based Learning: A Systematic Review
9.	(Rosyidah & Subekti, 2023)	Journal Pijar MIPA	Implementation of Socio-Scientific Issues Learning to Improve Students' Critical Thinking Skills
10.	(Amalia et al., 2024)	Unnes Science Education Journal	The Effectiveness of an E-Module Based on Socio-Scientific Issues to Improve Critical Thinking
11.	(Utomo et al., 2020)	Jurnal Pendidikan IPA Veteran (JIPVA)	The application of the socio-scientific issue (SSI)-based problem-based learning model on the critical thinking skills of junior high school students
12.	(Usman & Anwar, 2024)	Journal of Natural Science and Integration	Development of Socio-Scientific Issues-Based Worksheets to Increase Learning Interest and Critical Thinking Skills of Students on Buffer Solution Material
13.	(Rahmawati et al., 2022)	International Journal of Education and Research	The Critical Thinking Skills Profile of Pre-Service Chemistry Teachers on Global Environmental Problems in The Socio-Scientific Issues (SSI) Context
14.	(Normawati et al., 2022)	Jurnal Penelitian Pendidikan IPA (JPPIPA)	The Effectiveness of Socio-Scientific Issues-Based Electronic Student Worksheet to Improve Critical Thinking Skills For Class VII Students
15.	(Fitroty et al., 2023)	Journal of Natural Science Educational Research	Problem-Based Learning Using a Socio-Scientific Issue Approach Assisted by Bulletins to Improve Students' Critical Thinking
16.	(Sari et al., 2024)	Educational Studies and Research Journal (ESRJ)	A Systematic Review on Integrating SSI into Science Education: Its Impact on 21st Century Skills (2014-2024)
17.	(Sulistiani et al., 2022)	Journal of Education Technology	E-modules with Android Appy Pie Based on Socio-Scientific Issues to Improve Students' Critical Thinking Skills
18.	(Busyairi & Kusuma, 2023)	SAR Journal	The Effectiveness of the Problem-Based Learning Model with Socio-Scientific Themes in Improving Critical Thinking Skills
19.	(Ragil et al., 2025)	Multidisciplinar	Socio-Scientific Issue Approach to Enhance Critical Thinking Skills: A Prisma Systematic Literature Review
20.	(Prastika & Arianingrum, 2024)	Jurnal Pendidikan MIPA	The Socio-scientific Issues Approach in Chemistry Education: A Literature Study and Its Implications
21.	(Dewi & Yahdi, 2025)	Jurnal Pendidikan MIPA	Research Trends on Socio-Scientific Issues in Chemistry Learning: A Systematic Review
22.	(Busyairi & Kusuma, 2023)	Jurnal Kependidikan	Digital Worksheet Transformation for Contextual Learning: Integration of PBL, SSI, and STEM
23.	(Husniyyah et al., 2023)	International Journal of Recent Educational Research (IJORER)	Scientific Literacy Improvement Using Socio-Scientific Issues Learning
24.	(Monaliza & Miterianifa, 2023)	Journal of Natural Sciences	The Use of Socio-scientific Issues In Science Learning: Review of Literature
25.	(Alpianti & Amelia, 2025)	Jurnal Penelitian Pendidikan Sains (JPPS)	Infusing Learners' Problem-Solving Skills Through Problem-Based Learning Model Assisted Socio-Scientific Issues (SSI)

No.	Author	Publisher	Article Title
			Worksheet on Environmental Pollution
26.	(Nurtamara et al., 2019)	International Education Studies	The Effect of Biotechnology Module with Problem-Based Learning in the Socio-scientific Context to Enhance Students' Socio-scientific Decision-Making Skills
27.	(Lubis et al., 2022)	International Journal of Instruction	The Effectiveness of Problem-based learning with Local Wisdom oriented to Socio-Scientific Issues
28.	(Haviz et al., 2024)	Jurnal Pendidikan IPA Indonesia	The Use of OF Socio-Scientific Issues to Promote Prospective Biology Teachers' Scientific Literacy and Development
29.	(Ummah, 2025)	Berkala Ilmiah Pendidikan Biologi (BioEdu)	Validity of LKPD Based on Socio-Scientific Issues (SSI) Environmental Change Material to Train Students' Reflective Decision-Making Skills
30.	(Liu & Tu, 2024)	Journal of Logistics, Informatics and Service Science (JLISS)	Improving Critical Thinking through AI-Supported Socio-Scientific Issues Instruction
31.	(Zahra et al., 2021)	Pancasakti Science Education Journal	The Influence of the Treffinger Model Based on Science and Social Issues on Critical Thinking Skills
32.	(Santika et al., 2018)	Journal of Physics: Conference Series	Analysis of students' critical thinking skills in socio-scientific issues of biodiversity subject
33.	(Arika et al., 2021)	International Joint Conference on Science and Engineering (IJCSE)	Bibliometric Analysis of Socio-Scientific Issues (SSI) in Physics (2019-2020)
34.	(López-Fernández et al., 2022)	Journal of Chemical Education	How Can Socio-scientific Issues Help Develop Critical Thinking in Chemistry Education? A Reflection on the Problem of Plastics
35.	(Pauzi & Windiaryani, 2021)	Jurnal Pendidikan Biologi (Biosfer)	Critical thinking skills on the global warming issue: Effect of the socio-scientific problems approach on problem-solving among students

The relationship between articles was revealed through analysis of titles and abstracts that had been adjusted to the research variables. Based on the mapping results obtained using VOSviewer software, a mapping visual was created that displayed the interconnected variables between articles. Terms that frequently appeared together or had similar meanings were then mapped into the same cluster.

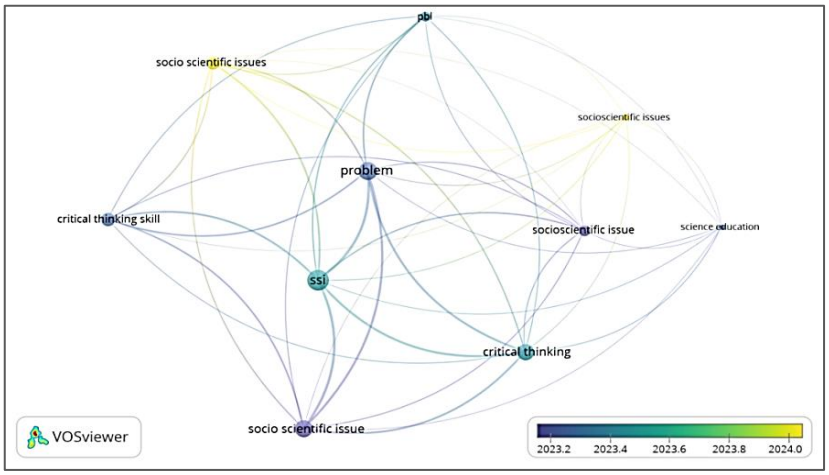

Figure 2. Visualization of Keyword Network Results from VOSviewer Analysis

The image was created to identify and interpret research gaps based on color visualization. The colors in the visual network of keywords reflect the average year of appearance of each term or keyword in the

analyzed literature. The VOSviewer visualization map shows that clusters with keywords related to PBL, SSI, and critical thinking are strongly connected, illustrating the research focus on integrating problem-based learning and socio-scientific issues to improve critical thinking skills. However, there are small clusters containing keywords such as assessment, worksheet, and digital literacy that are relatively far from the core clusters. This suggests that research on the development of learning tools and assessments to support PBL-SSI integration remains limited. The imbalance between the dominance of studies on the effectiveness of PBL–SSI implementation and the lack of research on evaluation instruments and technological support indicates a significant research gap. Thus, further research is needed to explore the development of critical thinking assessment instruments, learning tools (e.g., student worksheets, digital modules), and applicable implementation strategies so that PBL–SSI integration can be more widely applied in biology learning.

Table 2. Keyword Clustering Based on VOSviewer Analysis

Cluster Color	Keywords	Cluster Description
Deep Blue	Science Socio-scientific issue Science education	This dark blue cluster is the first basis of the research being discussed. It highlights the main ideas that have been prevalent for a long time and are frequently referenced in written works. The existence of terms such as science education and socio-scientific issues marked in dark blue indicates that these have long been the focus and a reference for further research. This color represents the theoretical framework or core themes of various studies that have been previously conducted.
Deep Green	Problem Critical thinking PBL	This bluish-green color indicates a direct application to learning models, such as Problem-Based Learning (PBL), and 21st-century educational goals, including critical thinking. This stage is a transitional stage, where researchers begin to apply ideas developed from initial theories into more practical methods or approaches in the classroom.
Green	SSI PBL	The green cluster is the focus of current research, which is shifting towards the integration of various concepts. For example, SSI is being used more widely and practically, and is being implemented through specific learning models, such as Problem-Based Learning (PBL). This stage indicates that researchers are starting to design learning interventions that integrate the PBL approach with social issues related to science (SSI). This color symbolizes a period in which educational concepts and strategies are collaborating.
Deep Yellow	Socio-scientific issues Critical thinking skill	This cluster demonstrates a deep focus on improving critical thinking skills, not only in general terms, but also in more specific forms, such as assessable skills. This is also linked to real-life situations involving scientific decision-making processes by students, such as those related to socio-scientific issues.
Yellow	Socio-scientific issues	The socio-scientific issues highlighted in yellow indicate that these themes are now the primary focus, possibly as a response to environmental problems or other social challenges that impact the education system.

Based on the review results, the most dominant research method used was quantitative, with experimental designs. Additionally, several articles employed qualitative and R&D approaches in accordance with their respective research designs. The following table summarizes the research methods and designs.

Based on an analysis of 35 selected articles, it was found that quantitative research methods were the most dominant approach used, with 17 articles. Most studies using this method employed experimental or quasi-experimental designs to assess the effectiveness of applying Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI) on improving students' critical thinking skills. Generally, the studies used a pretest-posttest design with a control group and analyzed the data using statistical tests such as t-tests, ANOVA,

and N-Gain calculations. This approach enabled researchers to objectively and quantitatively assess the direct effect of the SSI-PBL model on learning outcomes.

Table 3: Recapitulation of research methods

Type of research method	Number of articles	Description
Quantitative	17 Article	Using experimental designs such as pretest–posttest
Qualitative	13 Article	Includes descriptive research, case studies, systematic reviews, reflective studies, and bibliometric studies that describe processes, trends, or conceptual findings.
Research and Development (R&D)	5 Article	Focusing on the development of ADDIE or 4D model products that have been tested for validity and practicality.

However, because most of these studies are quasi-experimental, there are still limitations in controlling for external variables and randomizing samples. This can affect the internal validity of the research, so that the results of improved critical thinking skills cannot be entirely attributed to a single treatment. Nevertheless, the majority of studies show a significant improvement in critical thinking skills, confirming the effectiveness of the SSI–PBL model in the context of science education in Indonesia.

Meanwhile, 13 articles use qualitative methods, with descriptive research designs or literature reviews. These studies focus on describing the implementation process, the perceptions of students and teachers, and reflections on the application of SSI-based learning. Some of them are also systematic reviews or literature studies, which aim to synthesize previous research results to identify patterns, trends, and the effectiveness of the SSI-PBL model in developing 21st-century skills. The qualitative approach offers a deeper conceptual understanding of how PBL and SSI impact students' mindsets and engagement, although it is not designed to measure these effects quantitatively.

Table 4: Recapitulation of research design

Type of Research Design	Number of articles	Description
Experiment / Quasi-Experiment	17 Article	Used to test the effectiveness of a learning model.
Literature Review	8 Article	Aims to map research trends and findings, as well as highlight the effectiveness.
Descriptive	5 Article	Describes the critical thinking or reflection ability of students or pre-service teachers, without experimental treatment.
Research and Development (R&D)	5 Article	Develops learning products such as LKPD (Student Worksheet/Worksheet), e-modules, or digital teaching materials, accompanied by expert validation and practicality testing,

Additionally, five articles employed the Research and Development (R&D) method. This design focused on the development and validation of learning products, including LKPD modules and SSI–PBL-based e-modules. The development models used varied, including ADDIE, 4D (Define, Design, Develop, Disseminate), and Borg & Gall. This type of research reinforces the direction of innovative learning development that is not only conceptually effective but also practical and feasible to implement in the classroom.

Overall, these results indicate that research on the application of PBL and SSI in enhancing critical thinking skills is predominantly driven by experimental quantitative approaches; however, recent trends suggest an increase in qualitative and R&D research. This signifies a shift in research orientation from

merely testing effectiveness to developing contextual and sustainable learning innovations, as well as a deeper conceptual understanding of how SSI and PBL work in improving students' critical thinking skills.

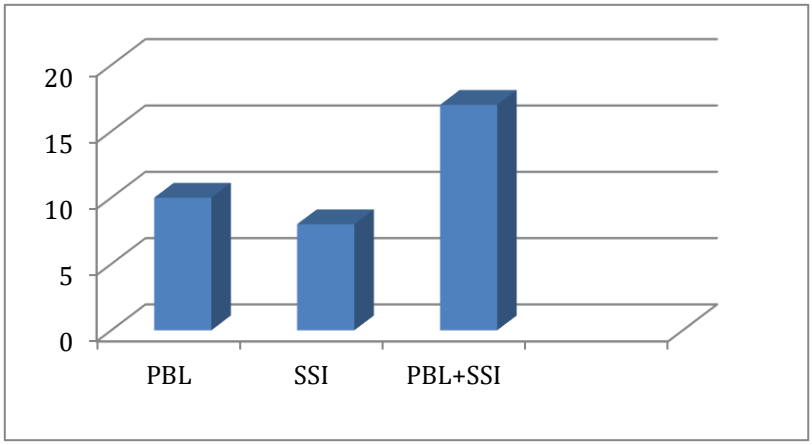

Figure 3. Distribution of Number of Articles Based on Method

Based on Figure 3, of the total 35 articles analyzed, 10 studies employed the PBL model, eight studies utilized SSI, and 17 studies combined both (PBL–SSI). The dominance of studies with a collaborative approach suggests that integrating PBL–SSI is considered more effective in developing students' critical thinking skills than a single application approach. The synthesis results show that approximately 68% of articles reported a significant increase in critical thinking skills, particularly through problem-solving and evidence-based argumentation activities. Studies with quantitative designs generally showed an increase in learning outcomes, while qualitative studies emphasized reflective thinking processes and scientific decision-making.

Temporally, research in the 2020–2022 period focused more on reviewing the conceptual aspects and effectiveness of PBL, while studies in 2023–2024 began to integrate SSI into PBL and develop issue-based biology learning tools. This shows a shift in the focus of research from the theoretical level to practical application in the classroom. However, research exploring the integration of PBL–SSI in the context of authentic assessment, digital literacy, and interdisciplinary studies remains limited, making it an important direction for further investigation.

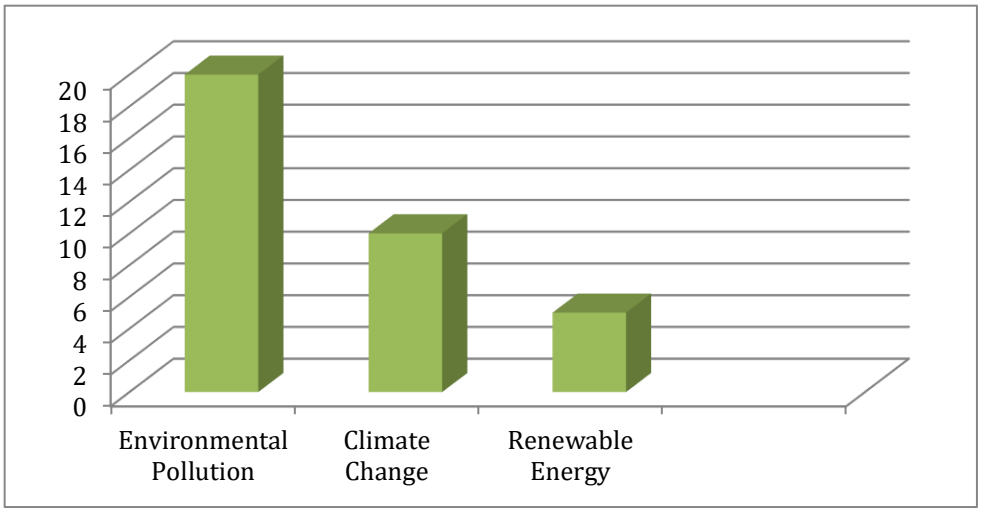

Figure 4. Distribution of Article Topics

The topic of environmental pollution dominated, with a total of 20 articles. This was followed by articles on climate change (10) and renewable energy (5). Environmental pollution is a dominant topic due to its proximity to students' daily lives, which is easily observable and can be directly linked to real-life

experiences, such as polluted rivers, plastic waste, or air pollution in the surrounding environment. When students discuss issues they face directly, their thinking tends to be more critical. For example, how students deal with domestic waste or the impact of industry on rivers. In this context, students are asked to analyze, consider from various perspectives, and formulate solutions based on data, values, and scientific arguments.

This dominance suggests that researchers often choose environmental issues as the context for SSI because these issues are easily linked to everyday phenomena, and empirical data are relatively easy to access. Conceptually, the concentration on environmental issues shows that scientific argumentation, problem solving, and evidence-based decision making in many studies are tested in the same domain, so that the empirical results obtained are relatively strong for the environmental context but less specific to be generalized to other scientific domains (e.g., biotechnology, health, food, and science ethics).

From a scientific contribution perspective, this pattern has two important implications. First, thematic synthesis reveals that evidence of the effectiveness of PBL–SSI integration on critical thinking skills in environmental issues is relatively consistent, allowing further studies in this domain to focus on instrument validation, cross-context replication, and larger-scale implementation studies. Second, the concentration of topics creates a clear research gap: the paucity of studies on non-environmental issues limits our understanding of whether and how PBL–SSI works on topics involving ethics, technology, or biotechnology. Therefore, future research should broaden the scope of themes (e.g., public health, food, genetic engineering) and compare the effectiveness of PBL–SSI across different topics to assess the generalizability of this pedagogical theory and model.

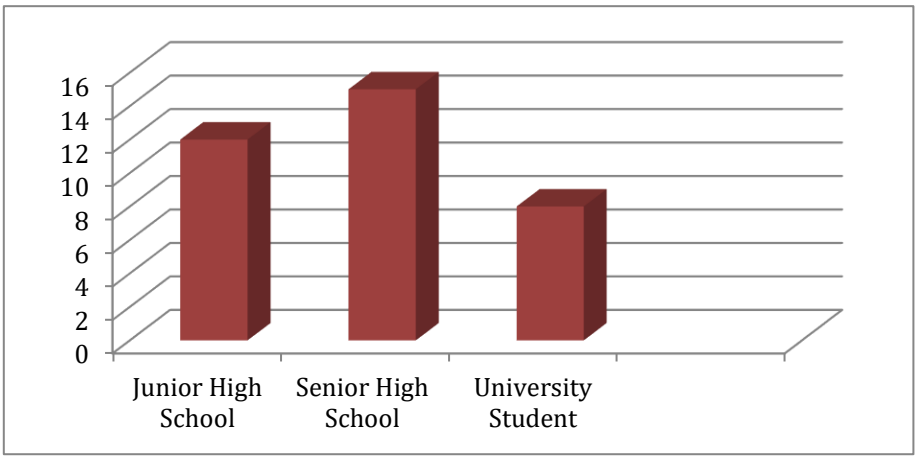

Figure 5. Distribution of Research Education Levels

Most studies reported senior high school ranked highest with 15 articles, followed by junior high school (12 articles) and university students (8 articles). This pattern indicates that the implementation of PBL–SSI is more focused on secondary education, possibly because the curriculum and capacity of high school students are more conducive to issue-based and problem-solving activities. The practical implication is that empirical evidence on the effectiveness of PBL–SSI is currently strongest in the context of high schools, making it easier to prioritize evidence-based policy and practice recommendations at that level.

Scientifically, this imbalance at the grade level raises two issues. First, there is a need to expand research to other levels of education (elementary school, teacher education, or community learning) in order to assess the initial readiness for critical thinking skills and PBL–SSI adaptation at various levels of cognitive development. Second, level differences require adjustments to intervention designs and instruments; for example, critical thinking instruments that are valid for high school students may not necessarily be valid for elementary school or prospective teacher students. Therefore, the scientific contributions needed are (a) studies on curricular adaptation and cross-level instrument validation, (b) longitudinal research to observe

the development of critical thinking from one level to the next, and (c) implementation studies that evaluate teacher readiness at each level.

Of the 35 articles, 28 studies (approximately 80%) reported a significant increase in students' critical thinking skills after the implementation of SSI-based PBL. The highest increase occurred in the context of science learning at the junior high and high school levels, primarily when teachers incorporated socio-environmental issues relevant to students' lives, such as waste, renewable energy, and public health. This demonstrates that the integration of PBL and SSI is not only effective in the cognitive realm but also in fostering scientific awareness and developing sustainable, reflective thinking skills. Thus, this thematic synthesis confirms that research trends in the field of PBL-SSI in Indonesia are shifting from merely testing effectiveness to developing contextual, reflective, and scientifically based learning innovations.

DISCUSSION

The results of the systematic literature review show that Socio-Scientific Issues (SSI)-based PBL contributes positively to the development of students' critical thinking skills in biology. This is evident from the 35 articles analyzed, with the majority of studies confirming an increase in students' analytical, evaluative, and argumentative skills when conducting SSI-based PBL (Fita et al., 2021; Dusturi et al., 2024). These findings align with Facione's (2015) opinion that critical thinking encompasses the ability to interpret information, analyze data, evaluate arguments, and draw logical conclusions. In addition, a meta-analysis study by Busyairi and Kusuma (2023) found that the PBL–SSI model has a large effect size on critical thinking skills, thereby strengthening the conclusion that this approach is consistently practical across educational levels.

More specifically, the problem orientation phase in PBL helps students develop their interpretation skills, as they are required to understand and interpret contextual socio-scientific issues, such as environmental or health issues. During the data collection and analysis phase, students develop their analytical skills by identifying causal factors, searching for scientific evidence, and distinguishing between relevant and irrelevant information (Sulistiani et al., 2022). Furthermore, group discussions and SSI exploration encourage evaluation and inference, where students assess the validity of arguments, consider various ethical perspectives, and draw conclusions based on scientific evidence (Rosyidah & Subekti, 2023). Finally, the presentation and reflection phase strengthens explanation skills as students are asked to construct logical arguments, explain proposed solutions, and reflect on the social implications of the decisions made. Similarly, Research (Putri et al., 2022), which focused on environmental change issues, reported a significant increase in high school students' evaluation skills, indicating that the PBL stages truly facilitate higher-order thinking processes.

Thus, the SSI-based PBL model not only fosters critical thinking skills in general but also develops each component of critical thinking systematically and in a contextualized manner. Social-scientific issue-based learning enables students to integrate cognitive, affective, and social aspects into the thinking process, so that the critical thinking developed is not only analytical, but also reflective and oriented towards responsible decision-making (Hernández-Ramos et al., 2021). Contextualization of issues in SSI has proven to be key, as students feel more engaged when the issues being studied are close to their lives.

In terms of implementing the PBL-ISU learning model in schools, it can make biology learning more contextual. In junior high school, simple issues such as plastic waste pollution and air pollution are used to foster students' initial interpretation skills (Utomo et al., 2020). In high school, more complex issues such as climate change and renewable energy successfully motivate students to evaluate data and develop scientific arguments (Nurtamara et al., 2019). At the master's student stage, especially among prospective science teachers, it was found that PBL-SSI not only improved their critical thinking skills but also strengthened their pedagogical skills in developing problem-based learning (Haviz et al., 2024). The findings of Liu and Tu (2024) confirmed that student teachers who learned using PBL–SSI showed significant improvements in their reflection and scientific decision-making abilities.

Several factors can also influence the effectiveness of implementing an SSI-based PBL model. The role of the teacher as a facilitator is the first factor because teachers who can ask provocative questions, guide discussions, and provide space for students to explore ideas can make learning more meaningful (Lubis et al., 2022). The second factor is student characteristics, which determine success. High school students, for example, are better equipped to handle complex issues than junior high school students, who still require intensive guidance (Normawati et al., 2022). The third factor is the context in which the issues are chosen. Research by Santika et al. (2018) indicates that issues closely related to everyday experiences yield greater improvements in critical thinking than abstract issues unfamiliar to students.

The analysis of 35 articles reveals that the application of the Socio-Scientific Issues (SSI)-based Problem-Based Learning (PBL) model significantly contributes to enhancing students' critical thinking skills in biology learning. The majority of studies (approximately 80%) report significant improvements in analysis, evaluation, and scientific argumentation following the application of this model. The PBL-SSI approach makes biology learning more contextual because students are directly confronted with social and environmental issues that are relevant to their lives. The consistency of these results reinforces that PBL–SSI is a robust and reliable learning approach for developing higher-order thinking skills in schools.

Thematically, the implementation of PBL–SSI in junior high schools generally focuses on simple issues, such as water pollution, plastic waste, or air pollution, which encourage students' initial interpretation and analysis skills (Utomo et al., 2020; Aisy & Trisnowati, 2024; Sulistiani et al., 2022). In high schools, more complex issues such as climate change, biotechnology, and renewable energy are used to train students in evaluation, inference, and scientific argumentation (Nurtamara et al., 2019; Pauzi & Windiaryani, 2021; Putri et al., 2022). Meanwhile, at the university level, particularly among science teacher candidates, research shows that the application of PBL-SSI not only improves critical thinking skills but also strengthens reflective pedagogical skills, especially in designing problem-based learning and integrating scientific social issues into the teaching context (Haviz et al., 2024; Liu & Tu, 2024; Rahmawati et al., 2022).

Although the results were positive, the implementation of PBL–SSI in practice encountered several challenges and limitations. First, many teachers were not yet ready to act as facilitators of open discussions, so learning tended to remain teacher-centered. Second, time constraints were an obstacle because issue-based learning requires in-depth data exploration and discussion. Third, differences in thinking abilities among students create gaps in participation, especially at the junior high school level, which still requires intensive guidance. Fourth, the availability of contextual learning resources in schools is also limited, so that not all issues can be studied with sufficient scientific data support (Masruro et al., 2021). Several studies recommend ongoing teacher training as a key strategy to overcome these barriers and ensure the successful implementation of PBL–SSI in schools (Busyairi & Kusuma, 2023).

Therefore, these findings suggest that biology teachers should be able to apply the PBL-SSI approach in their teaching. Teachers can use environmental and social issues as a primary means of teaching biological concepts, so that students not only understand the material theoretically, but also become accustomed to evaluating information, constructing arguments, and making responsible decisions. Thus, the application of PBL-SSI not only strengthens students' mastery of biology knowledge but also prepares them to face the challenges of the 21st century with better critical thinking skills.

Nevertheless, the consistent results from 35 articles demonstrate that integrating PBL and SSI is an effective strategy for developing critical thinking skills in biology students in Indonesia. This model focuses not only on cognitive outcomes but also on developing a reflective character and making evidence-based decisions. However, despite these findings, there is a lack of longitudinal and cross-level studies that explore the sustained and broader impact of this integration. To address this research gap, further studies with longitudinal designs and cross-level evaluations are needed. Thus, PBL–SSI can be seen as one of the most promising approaches to building a generation that is critical, scientific, and concerned about environmental and social issues.

CONCLUSION

A systematic literature review of 35 articles shows that integrating Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI) effectively improves students' critical thinking skills in biology learning. PBL facilitates student engagement in problem-solving, while SSI provides an authentic context relevant to everyday life. The combination of the two has been proven to encourage deeper interpretation, analysis, evaluation, and scientific conclusion-drawing skills. The study also reveals that environmental topics, such as pollution, climate change, and renewable energy, are most commonly used due to their relevance to students' experiences. Approximately 80% of studies reported a significant increase in critical thinking skills after implementing PBL–SSI, supported by scientific argumentation and evidence-based discussion activities. Bibliometric analysis (VOSviewer) also confirmed this positive trend by showing a strong connection among the keywords "PBL," "SSI," and "Critical Thinking." Additionally, the PBL–SSI model is more widely used than single applications because it offers stronger cognitive stimulation. Research with experimental designs consistently shows an increase in posttest scores, while R&D research confirms that media such as e-modules and digital worksheets can support learning effectiveness. This confirms that PBL–SSI can be widely applied in various science learning contexts.

Based on these findings, PBL–SSI is recommended for use in biology education because it fosters critical thinking skills, scientific literacy, and responsible decision-making. This approach also has the potential to be adapted to other subjects relevant to real-world issues. Further research is needed to develop authentic assessments and evaluate the long-term implementation of PBL–SSI so that its impact on the learning process and outcomes can be comprehensively understood.

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