

Development of an Environmental Problem-Based Learning Model to Improve the Social-Scientific Reasoning of Prospective Chemistry Teachers

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Abstract

This study aims to develop a valid, practical, and effective Environmental Problem-Based Learning (EPBL) model grounded in Socio-Scientific Reasoning (SSR) to enhance the socio-scientific thinking skills of prospective chemistry teachers. Using a Research and Development (R&D) approach with the ADDIE framework, the study designed and evaluated an SSR-based EPBL model integrating real-world environmental issues with reflective learning activities. The model focuses on strengthening key SSR dimensions, including issue complexity, multiple perspectives, continuity of inquiry, and skepticism of information. Results indicate that the SSR-based EPBL model significantly improves students' SSR capabilities, with high levels of instrument validity and reliability. Student responses were highly positive, particularly regarding engagement with local environmental issues and the use of data-driven argumentation. Expert validation confirmed that the model's syntax, learning tools, and assessment components meet both scientific and pedagogical standards. This model contributes to the advancement of contextual learning based on SSR and offers an alternative strategy for 21st-century science teacher education. The adoption of this model is recommended for other courses and faculty training programs to support transformative scientific literacy.

Keywords: environmental problem-based learning, socio-scientific reasoning, instructional model, chemistry education, Rasch model

1. Introduction

The challenges of 21st-century science education demand the development of higher-order thinking skills that are not limited to mere conceptual mastery. One critical skill in this regard is Socio-Scientific Reasoning (SSR), the ability to comprehend complex scientific issues embedded within social contexts, evaluate multiple perspectives, critically assess informational bias, and make evidence-based decisions. (Kinslow et al., 2018; Laliyo et al., 2025; Owens et al., 2022; Romine et al., 2017, 2020).

In Indonesia, strengthening SSR has become increasingly essential in the education of prospective science teachers. The 2022 PISA results, which revealed Indonesia's low performance in scientific literacy (Napitupulu, 2023; OECD, 2023) This underscores the weak reflective thinking abilities among students. This situation reflects a significant challenge in science education, which has traditionally focused more on laboratory procedures and rote memorization of concepts, with limited connection to real-world environmental and social issues relevant to students' lives (Owens et al., 2017, 2019, 2022).

International studies have long emphasized the importance of enhancing functional scientific literacy. For instance, Ke et al. (2021) and Kinslow et al. (2018) argue that scientific literacy must encompass understanding the interplay between science and society and the ability to apply both scientific and social models to examine complex issues such as pandemics, climate change, and environmental degradation. In this context, the Socio-Scientific Issues (SSI) approach has consistently been shown to enhance students' critical thinking, decision-making, and conceptual

understanding of science. Similarly, meta-analytic findings by Badeo and Duque (2022) confirm that SSI-based instruction substantially improves content mastery, decision-making, scientific competencies, and reasoning skills.

While such approaches have been explored globally, the Indonesian context still faces specific challenges. Existing research on SSI and problem-based learning (PBL) has primarily been applied in broader international or secondary school settings, often without adaptation to local socio-environmental issues or explicit integration into teacher education programs. Moreover, the design and validation of SSR assessment instruments—particularly those using the Rasch Model—remain underexplored in Indonesian higher education. Thus, this study does not claim to invent an entirely new pedagogical framework but rather adapts and contextualizes existing models such as PBL, SSI, and constructivist learning theory into an Environmental Problem-Based Learning (EPBL) model tailored to Indonesian teacher education.

EPBL emphasizes solving environmental problems through collaborative, reflective, and data-driven processes (Grooms, 2020). By integrating local socio-environmental contexts with inquiry-based learning, EPBL aims to facilitate not only scientific exploration but also the development of SSR through experiential learning and argumentative discussion. The novelty of this study lies primarily in the contextualized integration of EPBL and SSR within Indonesian chemistry teacher education, focusing on locally relevant environmental issues, and in the Rasch-based validation of SSR assessment instruments to ensure robust measurement of students' reasoning skills. Rather than proposing an entirely new pedagogical framework, this study adapts and extends existing approaches such as PBL, SSI, and constructivist learning theory to the Indonesian higher education context, addressing the need for contextually relevant instructional models and empirically validated assessment tools.

Accordingly, this study develops a locally contextualized EPBL model designed to strengthen the four dimensions of SSR among prospective chemistry teachers. By combining real-world problem-solving with reflective learning, the model is expected to make significant contributions both theoretically and methodologically to the field of science education, while also providing a strategic approach for shaping future teachers who are critical, reflective, and responsive to the socio-scientific challenges of the 21st century.

2. Research Objectives

This study aims to develop a locally contextualized EPBL model that integrates the dimensions of Socio-Scientific Reasoning (SSR) to enhance SSR abilities among prospective chemistry teachers. The proposed model not only incorporates a problem-based approach and authentic environmental issues but also includes a validated SSR assessment instrument based on the Rasch Model.

The development of this model is expected to contribute to:

1. Constructing a locally relevant EPBL learning syntax that supports the development of SSR.
2. Ensuring the validity and reliability of learning tools and instruments, particularly for quantitatively measuring the four dimensions of SSR.
3. Providing both pedagogical and practical foundations to improve the quality of teacher education in addressing the complexity of 21st-century socio-scientific issues.

3. Research Questions

This study seeks to address the following research questions:

1. What are the characteristics of a locally contextualized EPBL model designed to develop SSR among prospective chemistry teachers?
2. How valid and practical are the learning tools and SSR instruments developed within the EPBL model?
3. How effective is the EPBL model in enhancing students' SSR abilities, based on statistical testing and Rasch Model analysis?

4. Theoretical and Conceptual Framework

4.1 Socio-Scientific Reasoning (SSR) in Science Education

Socio-Scientific Reasoning (SSR) refers to a set of reflective and critical thinking competencies that individuals use to understand, evaluate, and respond to complex, value-laden socio-scientific issues. In this study, SSR follows Sadler's (2007) widely used framework consisting of four dimensions: recognition of complexity, consideration of

multiple perspectives, acknowledgment of the ongoing nature of scientific inquiry, and skepticism toward biased information. (Ben-Horin et al., 2023; Irmak, 2020; Sadler et al., 2007). Recent studies have shown that SSR requires not only scientific knowledge, but also integration with social domains such as ethics, economics, and politics. The ability to synthesize across these domains is essential for developing functional scientific literacy. (Kinslow et al., 2018; Roberts & Bybee, 2014).

4.2 Environmental Problem-Based Learning (EPBL) as a Pedagogical Approach

Environmental Problem-Based Learning (EPBL) is a learning approach rooted in real-world environmental issues that encourages learners to identify problems, evaluate data-driven information, and collaboratively develop solutions (Georgiou & Kyza, 2023; Grooms, 2020). In science education, EPBL connects classroom learning with local environmental issues, enabling students to integrate scientific concepts with social and ecological realities (Adlim et al., 2014; Daniel et al., 2004; Suryawati et al., 2020). For instance, a field investigation on water quality might not only develop conceptual understanding of chemical pollutants but also stimulate discussion on community health and environmental ethics. Such approaches enhance students' epistemic engagement, critical thinking, and civic awareness (Kinslow et al., 2018).

4.3 Constructivist and Socio-Constructivist Perspectives in Contextual Learning Design

While traditional constructivist theory (Piaget; Vygotsky) views knowledge as actively constructed through interaction with physical and social environments (Gulacar et al., 2020; Hancock et al., 2019), socio-constructivism extends this by emphasizing the cultural and dialogic dimensions of learning (Clarà, 2017; Rose & Fischer, 2009). Science-as-culture perspectives further highlight that science learning involves both cognitive reasoning and affective engagement with values, norms, and societal implications. Within EPBL, these frameworks collectively support experiential and discussion-rich learning environments, where students critically examine environmental problems while reflecting on ethical and cultural contexts shaping scientific practice.

4.4 Theoretical Integration in the Development of the SSR-Based EPBL Model

The proposed SSR-based EPBL model in this study represents a synthesis of environmental problem-based contextual learning (EPBL), the SSR framework, and constructivist principles. This model is designed to strengthen four core SSR competencies among prospective chemistry teachers through: (1) exploration of local environmental issues; (2) discussion and argumentation from multiple perspectives; (3) reflective learning on scientific uncertainty; and (4) critical evaluation of information sources. Moreover, by integrating field-based investigations with ethical reflection, the model balances cognitive reasoning with affective dimensions such as values, attitudes, and social responsibility. This integration aligns with the Vision II Scientific Literacy (Roberts & Bybee, 2014), which emphasizes the relevance of science within social contexts, and is supported by research highlighting the importance of holistic approaches in socio-scientific issue education (Sadler et al., 2016; Topçu et al., 2018; Zeidler & Kahn, 2014).

4.5 Conceptual Relationship in the Development of the SSR-Based EPBL Model

Figure 1 illustrates the conceptual integration underlying the SSR-based EPBL model, which is grounded in constructivist and socio-constructivist theories that frame learning as both experiential and socially mediated. Within this model, the Environmental Problem-Based Learning (EPBL) approach serves as the vehicle for engaging students in authentic, real-world environmental issues, while the Socio-Scientific Reasoning (SSR) framework provides the reflective and critical thinking dimensions necessary for informed decision-making. The connection between EPBL processes and SSR competencies is illustrated through concrete learning activities. For example, field observations of water pollution enable students to recognize the complexity of environmental problems; collaborative debates on waste management encourage them to consider multiple perspectives; and the analysis of conflicting media reports fosters skepticism toward biased information. Similarly, reflective learning tasks help students acknowledge the ongoing nature of scientific inquiry and the uncertainty inherent in addressing socio-environmental issues.

In addition to emphasizing cognitive reasoning, the model explicitly incorporates affective dimensions such as ethical reflection, values, and attitudes to ensure that students' decision-making processes integrate scientific evidence with moral and societal considerations. This cognitive-affective balance aligns with Vision II Scientific Literacy (Roberts & Bybee, 2014) and research advocating for holistic socio-scientific education (Sadler et al., 2016; Topçu et al., 2018; Zeidler & Kahn, 2014). Although the model was initially designed for an Environmental Chemistry course, its emphasis on authentic problem contexts, inquiry-based learning, and reflective reasoning makes it adaptable to other disciplines, including biology, physics, and interdisciplinary science education. Consequently, the SSR-based EPBL model offers a versatile framework for cultivating scientific literacy and

socio-scientific reasoning across diverse educational settings.

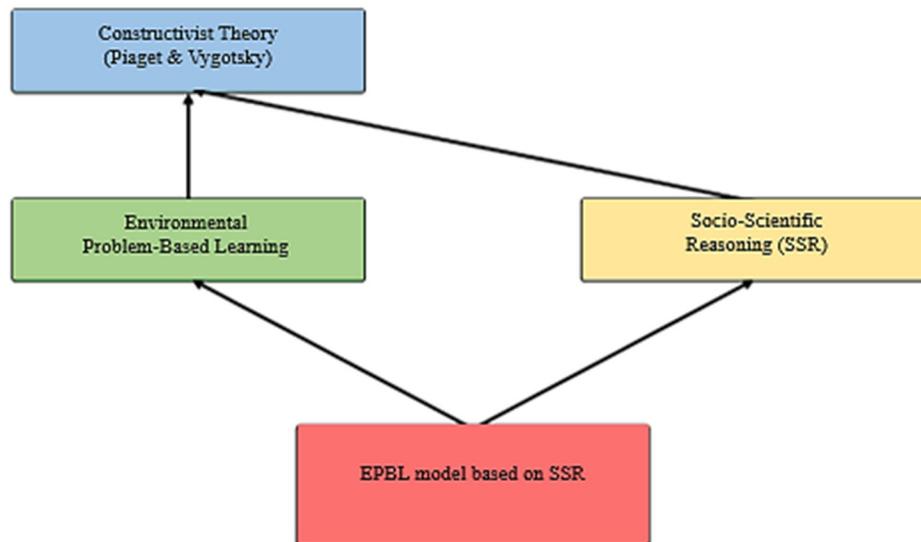


Figure 1. Conceptual Diagram of the Development of the SSR-Based Environmental Problem-Based Learning (EPBL) Model

5. Research Method

5.1 Research Design

This study employed a Research and Development (R&D) approach, utilizing the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model, as proposed by Branch (2009). This model was selected for its capacity to support a systematic process in designing and testing the effectiveness of instructional models. The effectiveness of the developed model was evaluated using a quasi-experimental design with a pre-posttest approach, which did not include a control group. (Creswell, 2012). Data analysis employed the stacking and racking techniques of the Rasch Model. (Ling et al., 2018; Wright, 2003). These standard techniques, introduced by Benjamin Wright, were used to measure the extent of changes in SSR achievement for each student and for each item over time before and after the implementation of the EPBL model. (Anselmi et al., 2015; Laliyo et al., 2022). This information was used to evaluate the effectiveness of the EPBL learning process and to adjust it to students' learning needs. (Ling et al., 2018). In addition, the analysis helped identify students who experienced learning difficulties and highlighted weaknesses in the implemented pedagogical innovation.

5.2 Research Subjects

The subjects of this study were prospective chemistry teachers enrolled at a public university in Indonesia. The model was tested in two phases: a limited trial involving 10 students and a broader implementation involving 47 students, all of whom participated in a course delivered using the EPBL model. Additionally, four expert validators, comprising university lecturers and education practitioners, were involved in assessing the model's validity and practicality. Participation in this study was entirely voluntary. All student participants were informed of the study's purpose and objectives before their involvement. Ethical considerations were upheld by ensuring that all collected data remained confidential and was used solely for the advancement of scientific knowledge. (Taber, 2014).

5.3 Model Development

5.3.1 Analysis Phase

The analysis phase aimed to comprehensively identify the gap between current chemistry teaching practices and the need to strengthen SSR competencies among prospective teachers. This analysis was conducted through a preliminary study that covered five key aspects: curriculum, course characteristics, instructional models used, student profiles, and a review of the scientific literature. A review of the *Merdeka Belajar Kampus Merdeka* (MBKM) curriculum revealed that, although it theoretically promotes contextual and project-based learning, its implementation in Environmental Chemistry courses tends to be procedural and falls short in fostering reflective and

cross-perspective reasoning. Instruction remains focused primarily on laboratory procedures and conceptual mastery, with limited integration of local environmental issues such as “pollution and ecosystem degradation in Danau Limboto” into course content. Instructional models such as Project-Based Learning and Case Study, while encouraging collaboration, have yet to cultivate students’ ability to analyze complex socio-scientific problems or make decisions grounded in data and values.

In addition, the student profile indicated a readiness to engage in active, field-based learning, while also highlighting the need for facilitation that promotes real-world problem exploration and critical reflection. A review of recent literature further supports the need for innovative instructional models that systematically develop SSR, particularly within the Indonesian context, where the Socio-Scientific Issues (SSI) approach has rarely been explicitly embedded in instructional design syntax. Thus, the findings of this analysis underscore the urgency of developing a contextual, reflective, and integrative EPBL model that responds to the demands of higher education, equipping prospective chemistry teachers with scientific thinking skills that are adaptive to 21st-century environmental and social challenges.

5.3.2 Design Phase

In this phase, the EPBL model was systematically designed based on the results of the needs analysis and grounded in the principles of contextual, collaborative, and inquiry-based learning. The primary objective of the model is to strengthen the SSR competencies of prospective chemistry teachers, particularly their abilities to think critically, construct evidence-based arguments, and reflectively evaluate socio-scientific issues. The model also targets short-term outcomes, including students’ ability to formulate critical questions, test hypotheses, and make socially responsible scientific decisions.

The EPBL syntax was developed based on a learning intervention framework that is both problem-oriented and inquiry-based (Figure 2). The learning process begins with the formation of student work groups, in which students establish learning contracts and assign roles according to collaborative functions. Next, students conduct preliminary observations of a local environmental issue, such as the degradation of the Danau Limboto ecosystem, through videos, popular science articles, and media reports. Further, students formulate critical questions to guide further exploration, which are then developed into initial hypotheses regarding the causes, impacts, and potential solutions to the identified environmental problems.

Learning Activity Flow of the EPBL Model

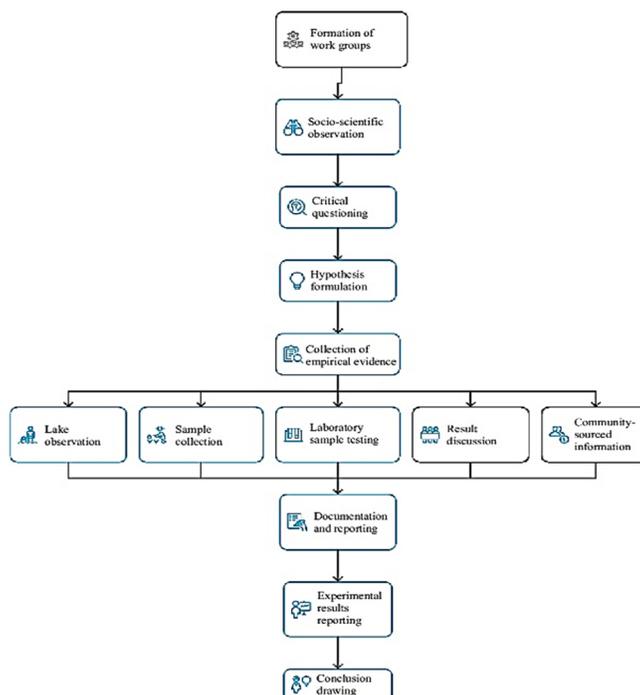


Figure 2. Learning Activity Flow of the Environmental Problem-Based Learning (EPBL) Model

The next phase, collecting empirical evidence, serves as the core of the scientific inquiry process. This stage involves direct observation at the lake site, sampling and laboratory testing, as well as interviews with residents to uncover social and cultural perspectives. All collected data are analyzed and discussed within student groups to construct an initial synthesis. Observations and experimental findings are recorded in individual logbooks and systematically documented. Students then compile a final report containing data analysis, evidence-based solutions, and reflections on the learning process. Students presented their reports in peer and lecturer discussions, which served as validation of their findings.

The final stage involves reflection and conclusion through the creation of a concept map. Students construct a conceptual structure that reflects the integration of scientific data, social realities, and proposed solutions. This process serves as a key indicator of SSR achievement, as it requires students to engage in skepticism toward biased information and to formulate decisions based on both ethical considerations and empirical evidence.

The EPBL learning scenario was designed for 12 class sessions under the central theme “*Polusi dan Kerusakan Ekologi di Danau Limboto.*” The instructional design adopts the approach of Tomasik et al. (2014) and integrates project-based learning, field experiments, and data-driven reflection, all based on local environmental contexts. The learning process involves group discussions, field observations, community interviews, and laboratory analysis of environmental samples, aiming to foster both cognitive and affective student engagement in solving problems scientifically and with social responsibility.

The assessment strategy in this model was holistically designed to measure all four dimensions of Socio-Scientific Reasoning (SSR). Evaluation was conducted using argumentation rubrics, engagement observation sheets, individual reflections, concept map analysis, and assessment of final products such as reports or papers. Both quantitative and qualitative methods were employed to ensure the validity of the results and to capture the authenticity of the learning process. In addition, instructional tools such as the Semester Learning Plan, student worksheets, field trip guides, and interview protocols were developed using a spiral approach to ensure continuity across topics and learning phases. SSR assessment instruments, including tests and questionnaires, were also prepared to support the validity and effectiveness of the model during the implementation and evaluation stages.

5.3.3 Development Phase

a. Development of Learning Materials

At this stage, the EPBL learning syntax was transformed into concrete, operational instructional materials ready for classroom implementation. The focus was to ensure that each component of the developed materials aligned with the EPBL learning syntax, SSR achievement indicators, and pedagogical principles that support contextual, collaborative, and reflective learning.

The development phase resulted in six core instructional components. First, the Semester Learning Plan outlines learning objectives, topics, time allocation, instructional methods, and assessment systems. Second, student worksheets containing step-by-step learning guides aligned with the EPBL stages, including open-ended questions designed to stimulate critical thinking. Third, a Field Trip Guide detailing procedures for site exploration, sample collection, and technical instructions for environmental observation. Fourth, an Observation and Interview Manual, featuring systematic instruments for collecting social data from communities around Danau Limboto. Fifth, SSR Assessment Instruments, comprising rubrics for evaluating student argumentation, reflection, final products (such as reports and presentations), and fieldwork processes. Sixth, multimodal supporting materials, including popular science articles, infographics, documentary videos, and spatial data, are designed to contextualize the environmental issues under investigation.

The initial instructional products were then subjected to a limited trial in an Environmental Chemistry class to evaluate the feasibility and usability of the model. The trial revealed increased student initiative in field exploration, active engagement in discussions, and improved ability to construct and communicate evidence-based scientific arguments. Based on the trial implementation, formative revisions were made to the materials. These included simplifying the language of instructions in the student worksheets to enhance clarity, adjusting the duration of field activities to increase efficiency, refining the assessment rubrics to fairly capture both process and outcomes, and strengthening the lecturer guidance mechanism to be more responsive to field dynamics.

The evaluation of the model development outcomes employed a triangulated approach, encompassing analysis of student learning outcomes based on pre–post SSR tests, their engagement throughout the learning process, and feedback from both lecturers and participants.

b. Instrument Development

As an integral part of the EPBL model development, an assessment instrument was also designed to measure students' Socio-Scientific Reasoning (SSR) abilities holistically. The structure of the instrument is based on four core dimensions of SSR, elaborated into ten specific indicators. These dimensions include: (1) the ability to identify complex socio-scientific problem categories, (2) the ability to analyze issues from multiple perspectives, (3) the ability to identify aspects of the problem requiring further investigation, and (4) the ability to recognize and critically evaluate potentially biased information (Romine et al., 2017, 2020). Each dimension is operationalized through indicators such as identifying cause-effect relationships, analyzing tensions between science and sociocultural values, examining stakeholder perspectives, proposing solutions, formulating specific research questions, prioritizing action plans, and constructing critical arguments in response to biased information (see Table 1).

Table 1. Dimensi SSR

SSR Dimension	Measured Aspect (Indicator)	Item
Identifying Complex SSI Categories	Able to identify issues situated in socio-scientific contexts	A1-Identification
	Able to describe issue categories arising from cause-and-effect relationships	A2-Causation
	Able to recognize conflicts between scientific and sociocultural aspects within complex SSI contexts	A3-Conflicting
Analyzing SSI from Multiple Perspectives	Able to identify differences in stakeholder opinions regarding solutions to pollution in Danau Limboto	B1-Difference of opinion
	Able to describe stakeholder perspectives on solutions to pollution in Danau Limboto	B2-Stakeholder solution
	Able to propose learner-generated solutions to pollution in Danau Limboto	B3-Learner solution
Identifying Aspects Requiring Further Investigation	Able to formulate specific research questions and follow-up actions for addressing pollution in Danau Limboto	C1(Specific question)
	Able to develop prioritized strategies for solving pollution issues in Danau Limboto	C2-Prioritized plan
Recognizing Potentially Biased Information with a Skeptical Attitude	Able to critically examine potentially biased information related to pollution in Danau Limboto	D1-Biased information
	Able to construct critical arguments explaining why certain information may be biased	D2-Why is information biased?

Each indicator was assessed through a single test item composed of two parts. The first part (Q1) asked students to identify phenomena that could be categorized as socio-scientific issues. For example, in Item A1, which assesses the ability to identify issues, students were instructed to select one statement among several options regarding pollution and ecological degradation in Danau Limboto that best reflects the socio-scientific complexity of the issue. The options included a range of pollution-related impacts, both ecological and social. The second part (Q2) was open-ended, requiring students to provide an empirical justification or reasoning for their choice in Q1 (see Table 2).

Student responses to Q2 were assessed using an analytic rubric on a 3-point scale. The rubric was designed to evaluate the quality of student justifications ranging from an inability to explain, to partial reasoning without sufficient evidence, to well-reasoned explanations supported by logical and empirical justification.

Table 2. Sample Item A1 – Socio-Scientific Reasoning (SSR)**Question 1 (Q1):**

The following statements describe pollution and ecological degradation phenomena occurring in Danau Limboto. In your opinion, which of these phenomena can be categorized as a socio-scientific issue?

- A. The high levels of sediment and water hyacinth have turned the water brown and degraded its quality.
- B. Due to declining water quality, several fish species have become rare and are at risk of extinction.
- C. Large amounts of waste and domestic wastewater have polluted and rendered the lake unsanitary.
- D. The expansion of agricultural land by local communities has significantly reduced the lake's surface area.
- E. The lake's water quality has worsened due to contamination by heavy metals and pesticides.
- F. The construction of embankments and roads along the lake has caused flooding in fishermen's housing areas and obstructed their access to fishing grounds.

Question 2 (Q2)

Provide empirical evidence and reasoning to support your answer to Q1

An example of the rubric's application can be seen in the A1 indicator (Identification), which assesses the ability to recognize socio-scientific issues. A score of 1 was assigned when a student was unable to provide any relevant explanation; a score of 2 when the student identified an issue but did not support it with strong empirical justification; and a score of 3 when the student explained the issue clearly and provided relevant, evidence-based reasoning (see Table 3).

Table 3. Example of Assessment Rubric for Item A1

Item	Assessment Criteria (Score)		
	1	2	3
A1-Identification:	Unable to identify any example of a socio-scientific issue.	Able to identify one example of a socio-scientific issue, but unable to provide appropriate empirical justification.	Able to identify one example of a socio-scientific issue and provide a well-reasoned justification supported by relevant empirical evidence.

The development of the SSR instrument aimed not only to measure learning outcomes but also to assess the quality of students' reasoning processes throughout the EPBL intervention. By integrating both cognitive and affective dimensions and emphasizing content validity through a clearly structured rubric, the instrument offers a comprehensive representation of students' SSR abilities.

5.3.4 Implementation Phase

This phase aimed to evaluate the implementation fidelity of the EPBL model syntax and examine students' responses in an authentic instructional context within the Environmental Chemistry course. The implementation focused on the local theme of “*Polusi dan Kerusakan Ekosistem Danau Limboto*”. To ensure the reliability of observations, inter-rater agreement was calculated and found to be exceptionally high, with a percentage of agreement score of 1.00. This indicates strong consistency between observers and reinforces the credibility of the implementation data. Observations were conducted continuously across all sessions, ensuring that the collected data accurately reflected the actual execution of the EPBL model. Student responses to the instructional model were assessed using a separately validated instrument. Independent observations revealed that students participated actively at every stage of the learning process. They were fully engaged in group discussions, enthusiastic during fieldwork activities, and demonstrated the ability to construct and deliver data-based scientific arguments collaboratively. The student activity observation sheet was also validated and confirmed to be highly valid across all components. Moreover, observation results showed high inter-rater reliability, confirming the consistency of evaluative judgments.

5.3.5 Evaluation Phase

The evaluation phase aimed to assess the overall quality of the EPBL model implementation. This evaluation focused

on two key aspects: the practicality and effectiveness of the model, both of which were measured using student response questionnaires and SSR skill tests administered before and after the instructional intervention. Practicality was assessed through two main instruments: an observation checklist for EPBL syntax implementation and a student response questionnaire. The observation checklist was designed to evaluate the extent to which the six stages of the EPBL instructional syntax were carried out as planned. Observations were conducted directly during the Environmental Chemistry course sessions. Meanwhile, the student response questionnaire consisted of 20 items using a five-point Likert scale. It was developed to explore students' perceptions regarding the ease of implementation, the meaningfulness of fieldwork experiences, and the relevance of the learning process to local environmental issues.

To evaluate the model's effectiveness, an SSR skills test previously subjected to content validation was administered using a one-group pretest–posttest design. The data were analyzed using the Rasch Model with Winsteps 4.5.5 software, which enabled the examination of item difficulty levels, person and item reliability, as well as student ability distribution in logit units. Before implementation, the SSR instrument had been assessed for both validity and reliability using Rasch fit statistics, including MNSQ and ZSTD, as well as reliability coefficients such as Cronbach's Alpha, item reliability, and person reliability (Laliyo et al., 2022; Laliyo et al., 2023)

6. Research Findings

The primary aim of this study was to develop an Environmental Problem-Based Learning (EPBL) model to enhance students' Socio-Scientific Reasoning (SSR) skills, particularly within the context of chemistry education. This section presents the results of expert validation of the proposed model, focusing on its content feasibility, design coherence, and logical structure before broader implementation in real classroom settings.

Model validation is a critical and systematic process in educational research and development, serving as the foundation for determining whether a proposed model meets theoretical, conceptual, and functional quality standards. The expert evaluations focused on the core dimensions of the instructional model, which reflect its scientific rigor, pedagogical soundness, and practical applicability.

6.1 Content Validity Results of the EPBL Model

The content validity of the EPBL model was assessed by four expert validators using an evaluation instrument in which each component was rated on a scale of 1 to 5. These scores were then converted into a percentage scale (0–100) to facilitate interpretation. The evaluation covered seven core aspects: (1) Supporting Theory (ST), which examined whether the model's theoretical and scientific foundation was strong and relevant; (2) Goal Rationality (GR), which assessed the logical flow and practical applicability of the learning activities; (3) Learning Model Syntax (LMS), referring to the alignment between the model's objectives and the instructional needs related to SSR; (4) Social System and Reaction Principles (SS&RP), which evaluated the degree to which the model supports pedagogical interaction and aligns with teaching principles in practice; (5) Learning Environment (LE), which considered how well the designed environment supports the development of students' skills; (6) Instructional and Accompanying Impact (I&IA), which assessed the model's potential to generate both intended learning outcomes and additional educational benefits; and (7) Overall EPBL Model Validity (VEPBL), which captured the validators' overall judgment of whether the model is complete, feasible, and ready for implementation in higher education settings.

Figure 3 presents the validation results of the EPBL model based on the assessments of four expert validators across seven development aspects: Supporting Theory (ST), Goal Rationality (GR), Learning Model Syntax (LMS), Social System and Reaction Principles (SS&RP), Learning Environment (LE), Instructional and Accompanying Impact (I&IA), and the overall validity of the EPBL model (VEPBL). The data indicate that the overall validity (VEPBL) received a perfect score from all validators, reflecting unanimous agreement that the model meets high standards of feasibility and quality.

In addition, the Goal Rationality (GR) and Instructional and Accompanying Impact (I&IA) aspects also obtained very high ratings across validators. These results suggest that the learning objectives embedded in the model are logically structured, practically applicable, and capable of generating both intended learning outcomes and positive accompanying educational impacts.

Furthermore, the Learning Model Syntax (LMS) aspect consistently achieved high scores, indicating that the instructional phases of the EPBL model are systematically organized and well aligned with the development of students' socio-scientific reasoning (SSR) skills. Slight variations in scores were observed in the Social System and

Reaction Principles (SS&RP) and Learning Environment (LE) aspects, where some validators assigned marginally lower ratings. This suggests that elements related to classroom interaction patterns and learning atmosphere may require further refinement during implementation.

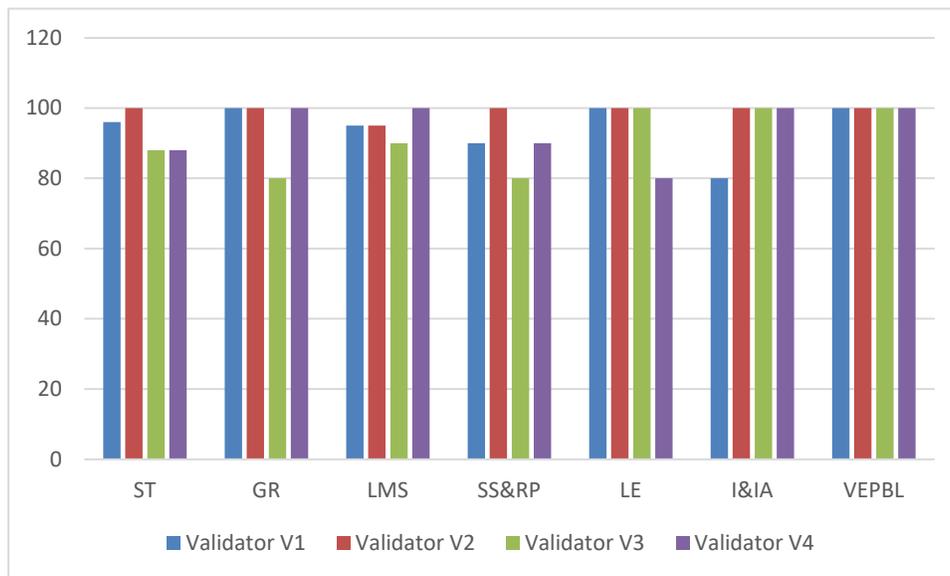


Figure 3. Content Validity Scores of the EPBL Model Based on Expert Validation Across Seven Aspects (ST, GR, LMS, SS&RP, LE, I&IA, and VEPBL)

Overall, the validation findings confirm that the developed EPBL model demonstrates strong content validity and is feasible for application in higher education contexts. Minor improvements are recommended primarily in the areas of social interaction management and learning environment optimization to further enhance the effectiveness of the model.

6.2 Practicality Results of the EPBL Model

The practicality of the EPBL model was evaluated through three main components: (1) the implementation fidelity of the model’s instructional syntax during the learning process; (2) the practicality of the instructional materials used, including the Semester Learning Plan, Student Worksheets, and Field Observation Guide; and (3) students’ responses to the implementation of the model. The evaluation was conducted in three phases: a limited trial, an extended trial, and full-scale implementation.

6.2.1 Implementation Fidelity of the Model Syntax

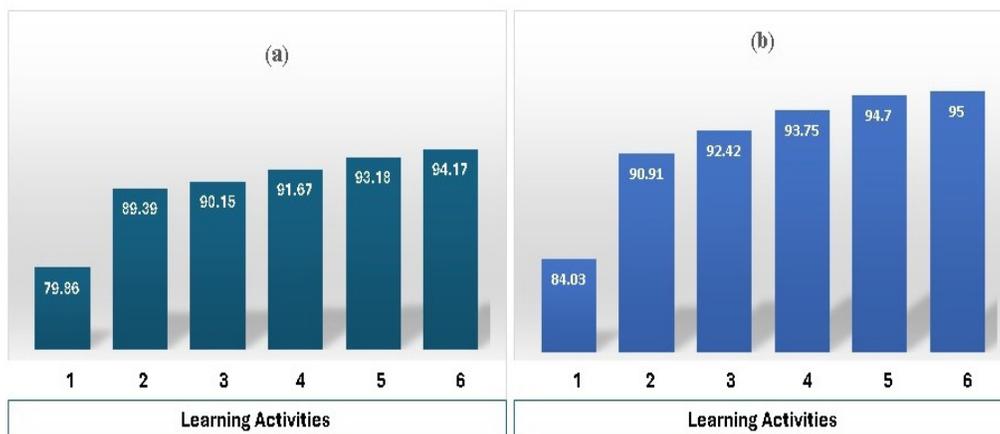


Figure 4. Percentage of EPBL Model Implementation in Small-Scale Pilot Classes (a) and Large-Scale Pilot Classes (b)

The implementation of the EPBL model syntax was observed by independent observers to evaluate its execution during each instructional session. Observation results indicated that all phases of the model were carried out effectively. The implementation chart (Figure 4) shows a stable and consistent trend throughout the learning sessions. During both the small-scale and large-scale trials, the implementation percentages for each phase ranged from 90% to 98%, with an overall average exceeding 94%, which is categorized as very high. These findings suggest that the model is highly practical and can be effectively applied in real-world educational settings, both in the classroom and in the field.

6.2.2 Practicality of the Instructional Materials

The practicality of the EPBL model's instructional materials was evaluated to ensure that the Semester Learning Plan, student worksheets, and observation and reflection guides could be implemented effectively and efficiently. The evaluation focused on several aspects: content clarity, logical structure, alignment with the EPBL model syntax, ease of implementation by instructors and students, time efficiency, and the completeness of usage guidelines. Content clarity refers to how easily the materials can be understood and followed by users. Logical structure pertains to the sequencing of content and activities, which should consistently reflect the EPBL syntax. Ease of implementation reflects the usability of the materials in real instructional settings without causing technical burdens or confusion for users. These aspects were assessed using a Likert scale, then converted into percentage-based feasibility scores.

Table 4. Results of Practicality Analysis of EPBL Model Devices

No	Evaluated Aspect	Model Implementation Observation Sheet		Student Activity Observation Sheet	
		Average Score	Validity Category	Average Score	Validity Category
1	Instructions	88%	Highly Valid	100%	Highly Valid
2	Content	92%	Highly Valid	92%	Highly Valid
3	Language	100%	Highly Valid	100%	Highly Valid

Based on Table 4, the validation scores of the EPBL model instructional tools ranged from 84% to 96%, falling within the "highly practical" category. This indicates that, according to the validators, all components of the EPBL model are logically structured, contextually relevant, and user-friendly for both classroom and field-based applications. No significant issues were reported in terms of technical execution or time allocation, reinforcing the notion that these instructional tools effectively support the implementation of the EPBL model's syntax. These findings thus confirm that the EPBL instructional tools are not only valid in terms of content but also highly practical for real-world learning environments that require active interaction, critical reflection, and meaningful learning experiences.

6.2.3 Practicality of Activities and Student Responses

The practicality of student activities and responses to the implementation of the EPBL model was assessed through a student response questionnaire and direct observation of student engagement during the learning process. The questionnaire comprised 20 items that reflected key aspects of practicality from the students' perspective, including field learning experiences, the relevance of the environmental issues addressed, the meaningfulness of reflective and critical discussion activities, the ease of following learning steps, and the level of participation in both group and individual tasks. Each item was rated using a 5-point Likert scale, with reverse scoring applied for negatively worded statements.

Based on Figure 5, 91.49% of students rated the EPBL model as "Very Good" (score range: 86–100%), with no respondents selecting the categories of "Fair," "Poor," or "Very Poor." This indicates a highly positive student perception regarding the model's practicality. The highest-rated indicators were related to direct field experiences and reflective engagement with real-world environmental issues, suggesting that students valued the integration of real-life contexts into the academic learning process.

In addition to the questionnaire data, field observations conducted by two independent observers during the pilot sessions revealed that students were actively engaged in every phase of the EPBL model, from field orientation and problem exploration to critical discussion, reflection, and action planning. While the observations were not quantified, the notes highlighted strong enthusiasm, active collaboration, and students' ability to present well-founded arguments based on field data. Throughout the learning process, no significant challenges were observed, either in terms of student participation or their understanding of the model's stages.

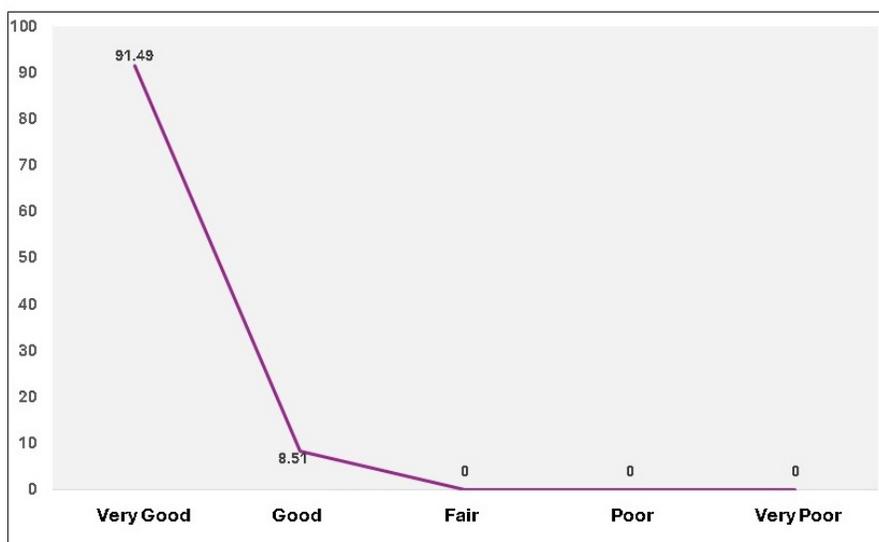


Figure 5. Student Responses to the Practicality of the EPBL Model

Overall, both the quantitative data from the student questionnaires and the qualitative findings from field observations indicate a very high level of practicality in implementing the EPBL model. The positive student responses and their high degree of active engagement serve as strong indicators that the model successfully fostered a contextual, collaborative, and cognitively rich learning process. Furthermore, it effectively facilitated the development of socio-scientific reasoning skills, one of the main objectives of this model's design.

6.3 EPBL Model Effectiveness Results

The effectiveness of the EPBL model was assessed to evaluate the extent to which the intervention improved students' socio-scientific reasoning (SSR) skills. The analysis was based on pre-test and post-test results collected using a validated SSR instrument and examined through stacking and racking techniques within the Rasch measurement framework. The analysis began with evaluating the reliability and validity of the measurement, followed by a stacking analysis to detect changes in ability levels for each student and each item between the pre- and post-intervention phases.

6.3.1 Rasch Analysis Properties of the Instrument

Table 5. Output Item Fit Order

Item Code	Outfit		PT Mea.Corr	Fulfilled/Not Fulfilled	Description
	MNSQ	ZSTD			
A1	0.74	-1.1	0.73	Fulfilled	Compliant
A2	1.09	0.5	0.69	Fulfilled	Compliant
A3	0.83	-0.8	0.74	Fulfilled	Compliant
B1	1.91	2.4	0.69	Fulfilled	Compliant
B2	1.53	1.5	0.63	Fulfilled	Compliant
B3	1.09	0.3	0.59	Fulfilled	Compliant
C1	1.22	0.9	0.70	Fulfilled	Compliant
C2	0.45	-1.4	0.70	Fulfilled	Compliant
D1	1.36	0.9	0.75	Fulfilled	Compliant
D2	1.21	0.9	0.68	Fulfilled	Compliant

Table 5 presents the results of the item fit statistics analysis. An item is considered misfitting if it fails to meet all three of the following criteria: Outfit Mean Square Residual (MNSQ) within the range of $0.5 < y < 1.5$; Outfit

Standardized Mean Square Residual (ZSTD) between -2 and +2; and Point Measure Correlation (PTMEA CORR) within $0.4 < x < 0.8$ (Boone et al., 2014). Based on the table, all items meet the specified criteria, indicating that the items fit the Rasch model appropriately. Therefore, the instrument can be considered valid for assessing students' socio-scientific reasoning (SSR) abilities (Laliyo et al., 2022).

Table 6 presents additional evidence supporting the instrument's construct validity. The item separation index value of 3.22 and the high item reliability of 0.91 logits indicate that the number of respondents was sufficient to confirm the item difficulty hierarchy, thereby supporting the construct validity of the instrument. (Linacre. 2020). A higher item separation index and reliability reassure the author that the item ordering is likely to replicate across different samples (Boone et al., 2014; Linacre). Furthermore, the person separation index of 1.52 and person reliability of 0.70 suggest that the instrument is adequately sensitive to distinguish between high- and low-performing respondents (Boone et al. 2014; Linacre. 2020). The Cronbach's Alpha coefficient of 0.88 indicates a strong interaction between the 94 respondents and the 10 items, reflecting excellent internal consistency and psychometric reliability of the instrument (Sumintono & Widhiarso, 2015).

Table 6. Person Separation and Reliability Statistics

	Measure	SD	Reliability	Separation	Cronbach Alpha (KR-20)
Person (N = 94)	1.11	2.44	.70	1.52	.88
Item (N = 10)	.00	1.14	.91	3.22	

6.3.2 Changes in Students' SSR Ability and Item Difficulty

Resp.	Pre	Post	Diff.	Resp.	Pre	Post	Diff.
01P	-1.73	4.04	5.77	25L	-2.65	4.04	6.69
02P	-0.53	1.07	1.6	26L	-0.01	1.73	1.74
03L	4.04	4.04	0	27P	-1.08	1.73	2.81
04P	-0.01	2.67	2.68	28P	0.51	4.04	3.53
05P	4.04	4.04	0	29P	-0.53	1.07	1.6
06P	-0.53	2.67	3.2	30P	-0.53	1.07	1.6
07P	-0.01	4.04	4.05	31P	-0.53	1.07	1.6
08P	-2.65	-0.53	2.12	32L	-0.53	1.07	1.6
09P	4.04	4.04	0	33P	1.07	4.04	2.97
10P	-1.08	2.67	3.75	34P	-0.53	1.07	1.6
11L	-1.08	4.04	5.12	35P	1.73	4.04	2.31
12P	-1.08	2.67	3.75	36P	-2.65	-0.01	2.64
13P	-0.01	2.67	2.68	37L	4.04	4.04	0
14P	4.04	4.04	0	38L	4.04	4.04	0
15P	4.04	4.04	0	39P	-1.73	1.73	3.46
16P	-0.53	1.07	1.6	40P	-1.73	-0.01	1.72
17P	-1.08	4.04	5.12	41P	0.51	4.04	3.53
18P	-4.01	4.04	8.05	42P	-4.01	4.04	8.05
19P	0.51	2.67	2.16	43P	-4.01	4.04	8.05
20P	-1.73	1.73	3.46	44P	-0.53	1.07	1.6
21P	1.73	1.73	0	45P	-4.01	-0.53	3.48
22L	-4.01	4.04	8.05	46P	-0.53	0.51	1.04
23P	-0.01	1.07	1.08	47P	-0.53	1.73	2.26
24P	-4.01	4.04	8.05				

Figure 6. Comparison of Students' SSR Abilities in the Pre-Test, Post-Test, and Pre-Post-Test Differences

According to the data presented in Figure 6, eight respondents (i.e., 03L, 05P, 09P, 14P, 15P, 21P, 37L, and 38L) showed no measurable change in their socio-scientific reasoning (SSR) ability. In contrast, 39 respondents (82.97%) demonstrated a significant improvement in their SSR performance.

The results of the item measure analysis (Table 6) indicate a significant shift in item difficulty levels before and after the intervention. All items demonstrated changes in difficulty, with item A2–Causation showing the largest decrease in difficulty between the pre- and post-test (-4.36), suggesting that this item became the easiest for students to answer following the implementation of the EPBL model. In contrast, item C1–Specific Question showed the smallest reduction in difficulty (-2.23), indicating that it remained relatively more challenging compared to the others after the intervention.

Table 7. Comparison of Item Difficulty Levels in Pre-Test and Post-Test Conditions

Item Code	Pre-test	Post-test	Difference Pre-Posttest
A1-Identification	1.70	-2.36	-4.06
A2-Causation	2.00	-2.36	-4.36
A3-Conflicting	2.17	-1.70	-3.87
B1-Difference of opinion	2.54	-0.23	-2.77
B2-Stakeholder solution	0.66	-1.99	-2.65
B3-Learner solution	0.04	-2.84	-2.88
C1-Specific question	2.00	-0.23	-2.23
C2-Prioritized plan	0.29	-2.84	-3.13
D1-Biased information	2.76	0.42	-2.34
D2-Why is information biased	1.42	-1.44	-2.86

Based on the measurement findings presented in Table 7, the EPBL model is shown to be highly effective in enhancing students' socio-scientific reasoning (SSR) skills. Based on the measurement findings presented above, the EPBL model is shown to be highly effective in enhancing students' socio-scientific reasoning (SSR) skills. The model's strength lies in its ability to engage cognitive processes through real-world problem-based learning, encouraging students to evaluate, analyze, and make decisions based on reflection and relevant evidence. This effectiveness is supported by: (1) the use of valid and reliable instruments, (2) statistically significant improvements in students' abilities, and (3) a consistent decrease in item difficulty following the learning intervention. Therefore, the EPBL model is strongly recommended for broader implementation in contextual learning at the higher education level, particularly in efforts to cultivate graduates who think critically, reflectively, and are evidence-based in addressing socio-environmental issues.

7. Discussion

This study demonstrates that the Environmental Problem-Based Learning (EPBL) model, grounded in Socio-Scientific Reasoning (SSR), effectively improves the socio-scientific reasoning abilities of pre-service chemistry teachers. Post-test results revealed significant gains across the four established SSR dimensions—issue complexity, multiple perspectives, continuity of inquiry, and skepticism toward information—indicating the model's capacity to foster critical, reflective, and socially responsible reasoning. These findings are consistent with prior studies by Sadler et al. (2007), Romine et al. (2017), and Kinslow et al. (2018), and extend their implications by embedding locally contextualized environmental problems and validating a structured instructional design tailored to environmental chemistry education.

A distinctive strength of the model lies in its contextual grounding in authentic environmental issues, such as pollution in Danau Limboto, which situates learning within socially meaningful contexts. This approach aligns with the Vision II Scientific Literacy framework (Roberts & Bybee, 2014), which emphasizes the integration of scientific understanding with ethical reasoning and civic engagement. The theoretical integration of Piagetian constructivism, Vygotskian social interactionism, and the Knowledge Community of Inquiry (KCI) framework supports collaborative inquiry and collective knowledge construction, offering a pedagogical structure that addresses both cognitive and social dimensions of learning more explicitly than conventional problem-based learning models.

Although the EPBL model was developed for Environmental Chemistry instruction, its core design principles—contextual inquiry, interdisciplinary reasoning, collaborative argumentation, and reflective evaluation of information—are transferable to biology, physics, and interdisciplinary STEM or sustainability-oriented courses. This adaptability positions the EPBL-SSR model as a flexible framework for promoting scientific literacy across diverse learning contexts, consistent with meta-analytic evidence showing that SSR-based instruction enhances students' reasoning quality and decision-making processes across disciplines (Badeo & Duque, 2022).

Importantly, while evidence-based decision-making emerged as a visible learning outcome during classroom implementation, it is conceptually embedded within the four SSR dimensions rather than treated as an independent construct. Students' capacity to evaluate evidence, question information credibility, and justify claims reflects the operationalization of skepticism toward information and continuity of inquiry as defined in Sadler's framework. This

clarification maintains theoretical alignment while acknowledging the instructional value of analytical decision-making skills fostered by the model.

Nevertheless, although the study confirms the model's validity, practicality, and effectiveness, its theoretical contribution remains incremental. Future research should conduct comparative studies between EPBL-SSR and alternative inquiry-based frameworks to examine whether socio-scientific reasoning-oriented designs yield distinct cognitive, epistemic, or affective advantages. Longitudinal and cross-disciplinary studies are also needed to evaluate scalability, sustainability of learning gains, and transferability across cultural and institutional contexts.

8. Implications and Limitations of the Study

This study contributes to the advancement of science pedagogy by introducing the Environmental Problem-Based Learning (EPBL) model, grounded in Socio-Scientific Reasoning (SSR), which integrates contextual approaches, constructivist principles, and socio-scientific reasoning. The model strengthens the implementation of Vision II Scientific Literacy by emphasizing value-based decision-making, evidence-based reasoning, and the integration of scientific knowledge with real-world social and environmental issues.

Practically, the EPBL-SSR model offers a strategic framework for instructors and curriculum developers to design science instruction that is both critical and contextually relevant. Its implementation has shown effectiveness in fostering students' reflective thinking on environmental problems while supporting faculty professional development to connect scientific content with socio-ecological challenges. The model has the potential to enhance key 21st-century competencies, including systems thinking, collaboration, ethical reasoning, and social responsibility, positioning it as a promising instructional approach across diverse educational contexts.

However, several methodological and conceptual limitations warrant consideration. While data collection was robust and triangulated—incorporating multiple instruments and validation measures—the absence of a control group and the use of a one-group pretest–posttest design weakened the internal validity of the findings. Moreover, the relatively modest sample size limits the generalizability of results beyond the immediate research setting. Future studies employing quasi-experimental or mixed-methods designs with larger, more diverse samples could yield stronger evidence for the model's effectiveness.

Certain assumptions underlie the interpretive stance adopted in this study. Emphasizing the integration of local environmental issues into science learning implicitly assumes that contextualization alone can foster deeper socio-scientific reasoning. However, students' reflective processes are complex and may be influenced by prior knowledge, cultural factors, and classroom dynamics that were not fully captured by the primarily quantitative approach employed. The absence of qualitative methods—such as think-aloud protocols, discourse analysis, or narrative inquiry—limits a deeper understanding of how students construct meaning during the learning process.

Finally, the scope of implementation was confined to an Environmental Chemistry course within a specific local context, restricting its immediate applicability across disciplines. Adaptation to other scientific domains—such as biology, physics, or interdisciplinary sustainability studies—and cross-cultural settings represents a key direction for future research. Broadening methodological approaches and exploring diverse contexts would provide a more nuanced understanding of how the EPBL-SSR model can inform a more humanistic, globally responsive science education capable of addressing the complex socio-scientific challenges of the 21st century.

9. Conclusion

The Environmental Problem-Based Learning (EPBL) model, grounded in Socio-Scientific Reasoning, offers a validated and practical instructional framework for strengthening pre-service teachers' reasoning competencies in addressing complex environmental issues. By systematically engaging learners in analyzing issue complexity, considering multiple perspectives, sustaining inquiry processes, and critically evaluating information sources, the model supports the development of reflective and socially responsible scientific reasoning.

The integration of real-world environmental contexts enhances learning relevance and encourages ethical awareness and civic responsibility, positioning the model as a meaningful contribution to contemporary science education. While the model demonstrates strong feasibility and instructional value, further empirical refinement through comparative and longitudinal research is necessary to strengthen its theoretical positioning and broaden its applicability across disciplines and educational contexts.

Overall, the EPBL-SSR model contributes a contextualized and empirically supported approach to inquiry-based science instruction, with promising potential to prepare future educators to engage thoughtfully with socio-scientific

challenges in the 21st century.

References

- Adlim, M., S, S., Ali, H., Ibrahim, A., Umar, H., Ismail, K., Gani, U. A., Hasan, I., & Yasin, B. (2014). Assessing Chemistry-Learning Competencies of Students in Isolated Rural Senior High Schools By Using the National Examination: a Case Study of Simeulue Island, Indonesia. *International Journal of Science and Mathematics Education, 12*(4), 817-839. <https://doi.org/10.1007/s10763-013-9440-x>
- Anselmi, P., Vidotto, G., Bettinardi, O., & Bertolotti, G. (2015). Measurement of change in health status with Rasch models. *Health and Quality of Life Outcomes, 13*(1), 1-7. <https://doi.org/10.1186/s12955-014-0197-x>
- Badeo, J. M., & Duque, D. A. (2022). the Effect of Socio-Scientific Issues (Ssi) in Teaching Science: a Meta-Analysis Study. *Journal of Technology and Science Education, 12*(2), 291-302. <https://doi.org/10.3926/jotse.1340>
- Ben-Horin, H., Kali, Y., & Tal, T. (2023). The Fifth Dimension in Socio-Scientific Reasoning: Promoting Decision-Making about Socio-Scientific Issues in a Community. *Sustainability (Switzerland), 15*(12), 1-23. <https://doi.org/10.3390/su15129708>
- Boone, W. J., Yale, M. S., & Staver, J. R. (2014). *Rasch analysis in the human sciences*. Springer Dordrecht Heidelberg New York London. <https://doi.org/10.1007/978-94-007-6857-4>
- Branch, R. M. (2009). Approach, Instructional Design: The ADDIE. In *Department of Educational Psychology and Instructional Technology, University of Georgia* (Vol. 53, Issue 9).
- Clarà, M. (2017). How Instruction Influences Conceptual Development: Vygotsky's Theory Revisited. *Educational Psychologist, 52*(1), 50-62. <https://doi.org/10.1080/00461520.2016.1221765>
- Creswell, J. W. (2012). *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research* (4th ed.). Boston: Pearson Education, Inc.
- Daniel, B., Stanisstreet, M., & Boyes, E. (2004). How can we best reduce global warming? School students' ideas and misconceptions. *International Journal of Environmental Studies, 61*(2), 211-222. <https://doi.org/10.1080/0020723032000087907>
- Georgiou, Y., & Kyza, E. A. (2023). Fostering Chemistry Students' Scientific Literacy for Responsible Citizenship through Socio-Scientific Inquiry-Based Learning (SSIBL). *Sustainability (Switzerland), 15*(8). <https://doi.org/10.3390/su15086442>
- Grooms, J. (2020). A Comparison of Argument Quality and Students' Conceptions of Data and Evidence for Undergraduates Experiencing Two Types of Laboratory Instruction. *Journal of Chemical Education, 97*(8), 2057-2064. <https://doi.org/10.1021/acs.jchemed.0c00026>
- Gulacar, O., Zowada, C., Burke, S., Nabavizadeh, A., Bernardo, A., & Eilks, I. (2020). Integration of a sustainability-oriented socio-scientific issue into the general chemistry curriculum: Examining the effects on student motivation and self-efficacy. *Sustainable Chemistry and Pharmacy, 15*(February), 100232. <https://doi.org/10.1016/j.scp.2020.100232>
- Hancock, T. S., Friedrichsen, P. J., Kinslow, A. T., & Sadler, T. D. (2019). Selecting socio-scientific issues for teaching: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science and Education, 28*(6-7), 639-667. <https://doi.org/10.1007/s11191-019-00065-x>
- Irmak, M. (2020). Socioscientific Reasoning Competencies and Nature of Science Conceptions of Undergraduate Students from Different Faculties. *Science Education International, 31*(1), 65-73. <https://doi.org/10.33828/sei.v31.i1.7>
- Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). Developing and Using Multiple Models to Promote Scientific Literacy in the Context of Socio-Scientific Issues. *Science and Education, 30*(3), 589-607. <https://doi.org/10.1007/s11191-021-00206-1>
- Kinslow, A. T., Sadler, T. D., & Nguyen, H. T. (2018). Socio-scientific reasoning and environmental literacy in a field-based ecology class. In *Environmental Education Research* (Vol. 4622). Routledge. <https://doi.org/10.1080/13504622.2018.1442418>
- Laliyo, L. A. R., Sumintono, B., & Panigoro, C. (2022). Measuring changes in hydrolysis concept of students taught

- by inquiry model: stacking and racking analysis techniques in Rasch model. *Heliyon*, 8(3). <https://doi.org/10.1016/j.heliyon.2022.e09126>
- Laliyo, L. A. R., Sumintono, B., La Kilo, J., & Panigoro, C. (2025). Changes in Students' Socioscientific Reasoning in an Environmental Chemistry Class: Application of Multi-Facet Rasch Model. *International Journal of Assessment & Evaluation*, 32(1).
- Laliyo, L. A. R., Utina, R., Husain, R., Umar, M. K., Katili, M. R., & Panigoro, C. (2023). Evaluating students' ability in constructing scientific explanations on chemical phenomena. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(9), em2328. <https://doi.org/10.29333/ejmste/13524>
- Linacre, J. M. (2020). *A User's Guide to WINSTEPS® MINISTEP Rasch-Model Computer Programs Program Manual 4.5.1*. Retrieved from www.winsteps.com
- Ling, M., Pang, V., & Ompok, C. C. (2018). Measuring Change in Early Mathematics Ability of Children Who Learn Using Games: Stacked Analysis in Rasch Measurement. In *Pacific Rim Objective Measurement Symposium (PROMS) 2016 Conference Proceedings*. Springer Singapore. <https://doi.org/10.1007/978-981-10-8138-5>
- Napitupulu, E. L. (2023). *Narasi Skor PISA Indonesia Jangan Seolah-olah Prestasi*. Kompas.Com.
- OECD. (2023). PISA 2022 Results Factsheets Indonesia. *OECD (Organisation for Economic Co-Operation and Development) Publication*, 1-9. Retrieved from https://www.oecd.org/en/publications/pisa-2022-results-volume-i-and-ii-country-notes_ed6fbcc5-en/indonesia_c2e1ae0e-en.html
- Owens, D. C., Sadler, T. D., & Friedrichsen, P. (2019). Teaching Practices for Enactment of Socio-scientific Issues Instruction: an Instrumental Case Study of an Experienced Biology Teacher. *Research in Science Education*. <https://doi.org/10.1007/s11165-018-9799-3>
- Owens, D. C., Sadler, T. D., Pettitt, D. N., & Forbes, C. T. (2022). Exploring Undergraduates' Breadth of Socio-scientific Reasoning Through Domains of Knowledge. *Research in Science Education*, 52(6), 1643-1658. <https://doi.org/10.1007/s11165-021-10014-w>
- Owens, D. C., Sadler, T. D., & Zeidler, D. L. (2017). Controversial issues in the science classroom. *Phi Delta Kappan*, 99(4), 45-49. <https://doi.org/10.1177/0031721717745544>
- Roberts, D. A., & Bybee, R. W. (2014). Scientific Literacy, Science Literacy, and Science Education. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 545-558). New York: Routledge.
- Romine, W. L., Sadler, T. D., Dauer, J. M., & Kinslow, A. (2020). Measurement of socio-scientific reasoning (SSR) and exploration of SSR as a progression of competencies. *International Journal of Science Education*, 42(18), 2981-3002. <https://doi.org/10.1080/09500693.2020.1849853>
- Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2017). Assessment of scientific literacy: Development and validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR). *Journal of Research in Science Teaching*, 54(2), 274-295. <https://doi.org/10.1002/tea.21368>
- Rose, L. T., & Fischer, K. W. (2009). Dynamic development: a neo-Piagetian approach. In U. Muller, J. Carpendale, & L. Smith (Eds.), *The Cambridge companion to Piaget* (pp. 400-421). Cambridge University Press.
- Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, 37(4), 371-391. <https://doi.org/10.1007/s11165-006-9030-9>
- Sadler, T. D., Foulk, J. A., & Friedrichsen, P. J. (2016). Evolution of a Model for Socio-Scientific Issue Teaching and Learning. *International Journal of Education in Mathematics, Science and Technology*, 5(1), 75. <https://doi.org/10.18404/ijemst.55999>
- Sumintono, B., & Widhiarso, W. (2015). *Aplikasi Pemodelan Rasch pada Assessment Pendidikan* [Application of Rasch Modeling in Educational Assessment] (Issue September). Penerbit Trim Komunikata, Cimahi. Retrieved from <https://www.researchgate.net/publication/282673464%0AAplikasi>
- Suryawati, E., Suzanti, F., Zulfarina, Putriana, A. R., & Febrianti, L. (2020). The implementation of local environmental problem-based learning student worksheets to strengthen environmental literacy. *Jurnal Pendidikan IPA Indonesia*, 9(2), 169-178. <https://doi.org/10.15294/jpii.v9i2.22892>
- Taber, K. S. (2014). Ethical considerations of chemistry education research involving "human subjects." *Chemistry Education Research and Practice*, 15(2), 109-113. <https://doi.org/10.1039/c4rp90003k>

- Tomasik, J. H., LeCaptain, D., Murphy, S., Martin, M., Knight, R. M., Harke, M. A., Burke, R., Beck, K., & Acevedo-Polakovich, I. D. (2014). Island explorations: Discovering effects of environmental research-based lab activities on analytical chemistry students. *Journal of Chemical Education*, 91(11), 1887-1894. <https://doi.org/10.1021/ed5000313>
- Topçu, M. S., Foulk, J. A., Sadler, T. D., Pitiporntapin, S., & Atabey, N. (2018). The classroom observation protocol for socioscientific issue-based instruction: development and implementation of a new research tool. *Research in Science and Technological Education*, 36(3), 302-323. <https://doi.org/10.1080/02635143.2017.1399353>
- Wright, B. D. (2003). Rack and Stack: Time 1 vs. Time 2 or Pre-Test vs. Post-Test. *Rasch Measurement Transactions*, 17(1), 905-906.
- Zeidler, D. L., & Kahn, S. (2014). *It's Debatable! Using Socioscientific Issues to Develop Scientific Literacy K-12*. National Science Teachers Association (NSTA) press. Arlington, Virginia.

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Authors contributions

Julhim S. Tangio and Lukman Abdul Rauf Laliyo were responsible for the study conception and design. Julhim S. Tangio, Frida Maryati Yusuf, Weny Musa, and Masrid Pikoli conducted the data collection and preliminary analysis. Julhim S. Tangio drafted the manuscript. Lukman Abdul Rauf Laliyo, Frida Maryati Yusuf, and Rustam Husain contributed to critical revision of the manuscript for important intellectual content. Lukman Abdul Rauf Laliyo served as the corresponding author and supervised the overall research process. All authors contributed to the interpretation of the results, reviewed the manuscript, and approved the final version for publication. Julhim S. Tangio and Lukman Abdul Rauf Laliyo contributed equally to this work.

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1. Preliminary summarization of datasets and literature to assist the authors in identifying key themes and organizing materials. All summaries were critically reviewed, substantially revised, and interpreted by the authors to ensure accuracy and fidelity to the original sources.
2. Structural drafting support, where AI was used to generate initial outlines or draft paragraphs based strictly on author-provided points, data, and arguments. All AI-generated text was thoroughly edited, rewritten, and validated by the authors. No AI-generated content was included without substantial human intellectual contribution.
3. Language refinement beyond basic grammar correction, including improving clarity, coherence, and readability. All substantive revisions affecting interpretation, analysis, or argumentation were made and approved by the authors.

AI tools were not used to generate original research data, conduct analysis, formulate core interpretations, or produce independent scholarly arguments. The authors confirm that they take full responsibility for the integrity, originality, and accuracy of the manuscript, in accordance with the ethical standards of the Committee on Publication Ethics (COPE) and the journal's guidelines on AI-assisted authorship.

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