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Development of Socio-Scientific Issue (SSI)-Based Student Worksheets on Green Chemistry within the Gold Mining Context to Enhance Students' Attitude toward Environment

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Abstract

Global demands for more responsible and sustainable mining practices make understanding environmentally friendly gold mining operations increasingly crucial. This context is particularly relevant in Gunung Mas Regency, Central Kalimantan, where small-scale gold mining practices have triggered socio-economic dilemmas between financial gains for the community and serious risks to the environment (mercury pollution) and health. This issue highlights the need for educational interventions that can bridge the concepts of chemistry with real socio-scientific issues (SSI). This study aims to develop a feasible, practical, and effective SSI-based Student Worksheet for Green Chemistry topic. The research method used was Research and Development (R&D) with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The SSI-based Student Worksheet was developed to encourage active learning, critical thinking, and student team collaboration in investigating and solving mining problems. A purposive sampling technique was applied to select one out of six tenth grade science classes at MA N 1 Sepang. The selected class, consisting of 20 Tenth-Grade Science students, was involved in the evaluation process, assessing the effectiveness of the product after its implementation in the class. The findings demonstrated that the developed SSI-based worksheet was highly feasible (teacher assessment average of 3,60) and highly practical for classroom use (student response rate of 87,68%). Furthermore, descriptive analysis revealed a positive shift in students' affective domain, characterized by the complete elimination of the 'Not enough' environmental attitude category and an increase in the proportion of students reaching 'Good' categories. In conclusion, while the SSI-based student worksheet was proven to be highly feasible and highly practical tool for enhancing students' attitude toward environment, its effect on students' long-term environmental attitudes remains relatively limited. This suggests that short-term interventions are insufficient to permanently change deep-rooted perspectives, and further comprehensive, long-term educational strategies are required.

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1. INTRODUCTION

Environmental pollution has become one of the most pressing global challenges due to the rapid expansion of industrial activities, urbanization, and the extensive use of chemical substances in agriculture, manufacturing, and domestic sectors. These activities generate hazardous waste and emissions that contaminate water, soil, and air, threatening ecosystem sustainability and human health (Janaki et al., 2023; Marques et al., 2020). Addressing these challenges requires not only technological innovations but also educational efforts that cultivate environmentally responsible citizens capable of making informed decisions regarding environmental sustainability. Consequently, chemistry education is expected to play a strategic role in preparing students to understand the chemical processes underlying environmental problems

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and to develop responsible attitudes toward environmental conservation.

One educational approach that supports this goal is Green Chemistry, which emphasizes the design and application of chemical processes and products that minimize hazardous substances, reduce waste generation, and promote sustainable resource utilization. Green Chemistry provides students with scientific knowledge and ethical perspectives for addressing environmental challenges through sustainable chemical practices (Cabrera-Franco et al., 2026). Nevertheless, understanding Green Chemistry concepts alone is insufficient to encourage environmentally responsible behavior (Constable, 2021). Students must also be provided with meaningful learning experiences that connect these concepts with authentic environmental problems, enabling them to apply scientific knowledge in real-world contexts and appreciate the environmental consequences of chemical practices (Wang et al., 2024).

In this regard, environmental attitude represents an essential educational outcome because it reflects individuals' beliefs, feelings, values, and behavioral tendencies toward environmental protection and sustainability. Environmental attitude encompasses cognitive, affective, and behavioral dimensions that influence individuals' willingness to participate in environmentally responsible actions (Lavuri et al., 2023). Previous studies have consistently demonstrated that positive environmental attitudes are associated with greater environmental awareness, responsible decision-making, and sustainable behavior (Suganthi, 2019). Therefore, fostering environmental attitudes should become one of the primary objectives of chemistry learning, particularly when addressing environmental issues closely related to chemical processes.

A promising instructional approach to achieving this objective is Socio-Scientific Issues (SSI), which integrates scientific concepts with authentic social and environmental problems requiring scientific reasoning, ethical judgment, and evidence-based decision-making (Jho, 2015; Laksono & Wibowo, 2022; Nam & Chen, 2017). Through SSI, students are encouraged to analyze controversial issues from multiple perspectives, construct scientific arguments, evaluate evidence, and consider the social, economic, and environmental implications of their decisions (Jia & Ren, 2025; Presley et al., 2013). Consequently, SSI not only enhances students' conceptual understanding and scientific literacy but also facilitates the internalization of environmental values, thereby strengthening their environmental attitudes.

To maximize the effectiveness of SSI instruction, it can be integrated with Problem-Based Learning (PBL), an instructional model that engages students in investigating authentic problems through inquiry, collaboration, discussion, and reflection (Tangio et al., 2026). Within SSI-based learning, PBL functions as the pedagogical strategy that guides students to identify environmental problems, collect and evaluate scientific evidence, propose alternative solutions, and justify their decisions using scientific reasoning (Lubis et al., 2022). Accordingly, Green Chemistry provides the scientific content, SSI offers authentic environmental contexts, while PBL facilitates the learning process through collaborative problem solving. The integration of these three components is theoretically expected to promote meaningful learning experiences that simultaneously improve conceptual understanding and cultivate positive environmental attitudes.

Socio-scientific context that strongly reflects these characteristics is artisanal and small-scale gold mining in Gunung Mas Regency, Central Kalimantan, Indonesia. Gold mining activities in this region involve the extensive use of mercury and, in some cases, cyanide during gold extraction, leading to serious environmental pollution and public health concerns (Athar et al., 2018; Azizah Rivani & Imam Santoso, 2023). Beyond chemical contamination, this issue also encompasses complex social, economic, and environmental dimensions, including community livelihoods, mining regulations, environmental justice, and post-mining restoration (Ramdhan, 2018). Therefore, the gold mining context provides a highly relevant SSI through which students can learn Green Chemistry principles while critically examining the environmental consequences of chemical applications and considering sustainable alternatives.

Previous studies have reported that SSI-based instructional materials and student worksheets effectively improve students' scientific literacy (Naim & Kolo, 2025), conceptual understanding, critical thinking(Sirmayeni et al., 2024), argumentation (Sparks et al., 2022), creativity, and problem-solving skills (Fitri et al., 2019). Likewise, integrating SSI with Problem-Based Learning has been shown to enhance learning motivation, collaborative skills, environmental awareness, and chemistry learning

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outcomes (Atta & Alghamdi, 2018; Nugroho & Budimarwanti, 2025). However, most existing studies have primarily focused on cognitive outcomes such as conceptual understanding, scientific literacy, and argumentation. Comparatively few studies have examined environmental attitude as the primary educational outcome of SSI-based instructional material development. Furthermore, previous SSI-based worksheets generally employed broad environmental themes and rarely incorporated Green Chemistry principles within authentic local environmental contexts, particularly those related to artisanal gold mining.

These limitations indicate a clear research gap. To date, limited attention has been devoted to developing SSI-based chemistry student worksheets that explicitly integrate Green Chemistry, Problem-Based Learning, and an authentic gold mining context with the specific objective of enhancing students' environmental attitudes. This integration is expected to provide students with opportunities not only to understand sustainable chemical principles but also to critically evaluate environmental issues, formulate evidence-based solutions, and internalize environmental values through meaningful learning experiences.

Therefore, this study aims to develop Socio-Scientific Issue (SSI)-based student worksheets on Green Chemistry within the context of artisanal gold mining and to investigate their effectiveness in enhancing students' environmental attitudes. The novelty of this study lies in integrating Green Chemistry principles, SSI, and Problem-Based Learning within an authentic local environmental context while positioning environmental attitude as the primary learning outcome. This study is expected to contribute both theoretically and practically to the development of contextual chemistry instructional materials that support Education for Sustainable Development and strengthen students' environmental responsibility.

2. METHOD

This Research and Development (R&D) study is focused on the design, development, and feasibility testing of instructional materials (Richey & Klein, 2009). The research framework follows the ADDIE development model, which systematically progresses through five stages: analysis, design, development, implementation, and evaluation.

The quality of the developed material was first assessed through expert judgment by a university-level academic and a professional chemist. During the development phase, two chemistry education faculty members specializing in green chemistry and learning media conducted the expert validation. Additionally, one chemistry teacher with a minimum of five years of teaching experience provided feedback to assess the feasibility of the developed SSI-based student worksheets.

Following this validation, a media's practicality test and its implementation in the class were performed. A total of 20 students from one Tenth-Grade Science class at Senior High School 1 Sepang were selected using purposive sampling out of six Tenth-Grade Science classes available. The participants consisted of 8 male and 12 female students. After the classroom implementation, learning outcome assessments and questionnaires were administered to evaluate students' conceptual understanding and environmental attitudes, respectively. Students' feedback on the practical utility of the worksheets was analyzed to ensure SSI-based worksheet feasibility.

By converting Likert scale responses into percentage scores, the validity was categorized across a predefined scale. The research instruments consisted of feedback sheets for expert judgment and questionnaires for students during the practicality testing phase. The product quality assessment instrument used for expert judgment was adapted from Hasnowo (2014), covering four criteria: content/material feasibility, presentation feasibility, linguistic and illustrative feasibility, and graphical feasibility.

The instructional media met the criteria for utilization only upon attaining at least a 'feasible' rating. The calculation of these percentage scores followed the procedure outlined in Formula 1.

$$X = \frac{\sum x}{n} \quad (1)$$

Notes:

X = average score of each component

Σx = total score of each component

n = number of expert judges

In alignment with the evaluative framework established by Lubis et al. (2022), the feasibility levels in this study were interpreted through a score-based classification system, where scores equal to or exceeding 3.26 were designated as 'highly feasible.'

Table 1. Feasibility level category

Average score	Category
3,26 – 4,00	Highly feasible
2,51 – 3,25	Feasible
1,76 – 2,50	Not enough feasible
1,00 – 1,75	Low feasible

The evaluation of instructional media's practicality typically employs observation checklists and questionnaires. Responses from both educators and learners are analyzed via Microsoft Excel using a percentage-based calculation. The resulting values are subsequently interpreted according to the criteria established in Table 2.

$$P = \frac{SRe}{SRh} \times 100\% \quad (2)$$

Notes:
P = average percentage
SRe = average achievable scores
SRh = maximum achievable scores

Table 2. Practicality category

%p	Category
85 < %p ≤ 100	Very practical
75 < %p ≤ 85	Practical
60 < %p ≤ 75	Quite practical
50 < %p ≤ 60	Not enough practical
0 < %p ≤ 50	Not practical

To assess students' environmental attitudes, a structured questionnaire was employed. The instrument consisted of 25 items using a 4-point Likert scale from 'strongly agree' to 'strongly disagree', therefore the minimun score is 25 and the maximum score is 100. It was developed in alignment with Rosenberg's tripartite model of attitude, comprising three distinct components, including: (1) cognitive (person's beliefs or certainties about an object). (2) affective (the feeling component that involves an individual's subjective emotional responses toward the object), and (3) The conative (behavioral tendency to act in certain manners regarding the presence of the object). Based on the validity process, the instrument achieved 82,34% as validity score. Furthermore, a pilot test was conducted with non-participating students to establish internal consistency, yielding a Cronbach's alpha reliability coefficient of 0.845, demonstrating that the instrument was highly reliable for empirical measurement.

Descriptive statistical analysis was employed to examine the quantitative data obtained from the environmental attitude questionnaire. Specifically, percentage distributions were calculated to profile and contrast the students' responses across the pretest and posttest phases. This descriptive approach allowed the researchers to clearly illustrate the baseline attitudes, post-intervention shifts, and the overall enhancement (*gain*) in students' environmental attitudes following the implementation of the SSI-based green chemistry worksheets.

$$p = \frac{\sum X}{\sum X_{max}} \times 100\% \quad (3)$$

Notes:
P = The percentage of the attitude score.
$\sum X$ = The total empirical score obtained by the students
$\sum X_{max}$ = The maximum possible ideal score

To systematically categorize the percentage results into the four determined levels (*unconcerned, somewhat concerned, concerned, highly concerned*), the percentage interval range (i) is calculated using the following formula:

$$i = \frac{\text{max score-min score}}{\text{number of categories}} x100\% \quad (4)$$

$$i = \frac{100\text{-}25}{4} \times 100\% = \frac{75\%}{4} = 18{,}75\%$$

Notes:
i = interval

Based on the calculation results above, students' attitudes toward the environment are classified as follows:

Table 3. Student attitude toward environment category

%p	Criteria
25,00% ≤ p < 43,75%	Not enough
43,75 % ≤ p < 62,5%	Enough
62,50% ≤ p < 81,25%	Good
81,25% ≤ p < 100,00%	Very good

3. RESULT AND DISCUSSION

3.1. Result

The analysis phase was conducted by evaluating the needs of the research subjects, encompassing the curriculum, subject matter, problematic contexts, and school conditions. Interviews were carried out to assess the current situation in schools,

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involving two teachers from the Gunung Mas Regency. The interview results revealed that while numerous gold mines are located in the vicinity of the schools, the existing learning resources have yet to integrate the gold mining context into the instructional process. Various suggestions and feedback were gathered during this stage; notably, due to suboptimal internet connectivity at the schools, it was decided that the SSI-based Worksheets and reading materials should not be developed in an electronic-based format. Specifically, the development of the SSI-based worksheet proceeded through four distinct stages:

1. Analysis

a. Target Analysis: This step involves identifying the intended users of the developed product. At this stage, specifically targeting tenth-grade high school students as potential users helps us analyze student and their cognitive development. Some findings regarding students:
   1) Tenth grade classes students (typically aged 15–16 years) are transitioning into the formal operational stage, making them pedagogically ready to develop critical thinking and scientific argumentation skills.
   2) From an environmental standpoint, mostl os students live in close proximity to local small-scale gold mining activities, meaning they interact daily with the socio-scientific issues being highlighted. Based on the distributed questionnaires, 61% of the students had previously seen or been to a small-scale gold mining area, and 54% of their parents or guardians worked within the small-scale gold mining sector

Analyzing these specific student characteristics ensures that the language, cognitive load, and contextual dilemma presented in the SSI-based worksheets perfectly match the students' developmental baseline.

b. Needs Analysis: This step entails evaluating existing instructional materials as the primary source of information in the classroom, as well as the availability of resources that support effective learning. This analysis serves to determine the specific types of instructional materials required to facilitate the learning process. At this stage, we concluded that there were no specific learning materials discussing green chemistry concepts directly related to the students' surrounding environment, particularly in the context of small-scale gold mining. Therefore, we decided to develop SSI-based student worksheets and the necessary reading materials to support classroom learning

c. Curriculum Analysis: This step involves examining the Learning Outcomes within the current curriculum. Based on curriculum analysis and the interview process with the teacher, we decided to construct the learning objective as below:
   1) To identify the chemical substances used in small-scale gold mining.
   2) To analyze the (alignment/misalignment) of green chemistry principles applied in small-scale gold mining activities.
   3) To identify the impacts of using chemical substances in small-scale gold mining.
   4) To find solutions for mitigating the negative impacts of using chemical substances in small-scale gold mining.

Consequently, the development of this product is tailored to these outcomes, resulting in the creation of socio-scientific issue (SSI)-based worksheet.

2. Design

The design phase involves the systematic planning of the Socio-Scientific Issue (SSI)-based book for chemistry topics. This phase encompasses several key activities:

a. Literature and Reference Compilation: Gathering relevant references and scientific literature to provide a robust theoretical foundation for the book's content.
b. Content and Assessment Development: Structuring the instructional materials and designing evaluation instruments (questions) to be integrated into the book.
c. SSI-Based Worksheet Framework: Designing the framework of the Socio-Scientific Issue (SSI)-based worksheet, which will serve as the primary activity guide for the product's users in chemistry learning

3. Development

The development phase aims to produce the Socio-Scientific Issue (SSI)-based book for chemistry topics. The procedures conducted during this phase are as follows:

a. Constructing the SSI-Based worksheet: Drafting and assembling the Socio-Scientific Issue (SSI)-based student worksheets tailored for chemistry instruction.

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b. Expert Validation: Subjecting the product to expert judgment by chemistry teachers to evaluate its theoretical and pedagogical validity.
c. Product Revision: Refining the instructional materials based on the feedback and corrective suggestions provided during the validation process.
d. Field Testing: Conducting a pilot trial with students to assess the practicality and usability of the product in a real classroom setting.
e. Final Refinement and Data Analysis: Utilizing feedback and suggestions from both expert judges and students to finalize the product. The collected data are then analyzed to determine the overall feasibility and quality of the developed materials.

In this stage, the developed product was tested through a limited-scale field trial with students. The validation process was conducted by a panel of experts, including a lecturer in Chemistry Education (as an expert in subject matter and pedagogy) and a chemistry teacher serving as a practitioner-validator. Based on the validation data obtained from both experts, the average scores for each assessed aspect are presented in the following table

Table 4. Expert Validation Result

Aspect	Average score
A. Content validity	
1. Conceptual Accuracy	3,33
2. Cognitive Appropriateness	4
3. SSI Syntax Integration	3,67
4. Scientific Authenticity	3
5. Inquiry Stimulation	3,33
Average	3,38
Category	Highly feasible
B. Language	
1. Grammatical Correctness	3,33
2. Readability and Clarity	4
3. Clarity of Instructions	4
4. Terminology Consistency	3
5. Narrative Engagement	3,33
Average	3,46
Category	Highly feasible
C. Content relevancy	
1. Contextual Relevance	4
2. Green Chemistry Alignment	4
3. Environmental Awareness Potential	4
4. Green Solution Orientation	4
5. Attitude Enhancement Support	4
Average	4
Category	Highly feasible
Total Average	**3,60**
Category	**Highly feasible**

The content validity aspect obtained an average score of 3.38 ('Highly Feasible'). Evaluators rated 'Cognitive Appropriateness' highest (4.00), confirming that the chemistry concepts match the development baseline of tenth-grade students. Similarly, 'SSI Syntax Integration' scored high (3.67), proving that the worksheet effectively guides students through structured SSI learning phases. However, 'Scientific Authenticity' received the lowest score in this aspect (3.00). This area required improvement; the experts suggested incorporating more precise, up-to-date scientific data and empirical evidence regarding the environmental impacts of local small-scale gold mining to enhance the authenticity of the dilemmas presented

The language aspect reached an average score of 3.46 ('Highly Feasible'). 'Readability and Clarity' as well as 'Clarity of Instructions' received perfect scores (4.00), demonstrating that the text is highly accessible and straightforward for secondary students. In contrast, 'Terminology Consistency' was identified as an area requiring improvement with a score of 3.00. Experts noted minor inconsistencies in shifting between local socio-environmental terms and formal chemical nomenclature, which was subsequently revised to ensure academic rigor. For instance, inconsistencies occurred in the alternating use of 'air raksa' and 'mercury', as well as the shifting terms between 'small-scale gold mining' and 'illegal gold mining.

Content relevancy aspect achieved a perfect average score of 4.00 ('Highly Feasible') across all five indicators. The Experts strongly agreed that the gold mining context is highly relevant to the students' immediate environment, effectively aligns with green chemistry principles, and holds substantial potential to foster students' environmental awareness and eco-conscious attitudes (*Attitude toward Environment*).

Minor revisions were subsequently implemented based on the feedback provided by the reviewers. The specific revisions undertaken are detailed below:

Table 5. Summary of revisions and modifications to the developed SSI-based worksheets

No	Aspect	Comment	Revision
1	Student orientation to the problem	The initial prompting questions are too complex and cannot yet be answered by	The presented questions have been further developed into: 1. In your opinion, is the mining

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No	Aspect	Comment	Revision
		students at the beginning of the lesson: 1. How is the traditional mining process conducted? 2. What chemical compounds are utilized in this process? 3. In your opinion, does the mining process affect environmental sustainability?	process safe for both the miners and the surrounding community 2. Do you have any questions regarding the process and impacts of small-scale gold mining? Please write down your questions!
2	Lay out	The captions or narratives for the presented images should ideally be placed alongside the respective images	The layout has been improved by placing the image narrative alongside the corresponding image
3	Critical discussion	Create specific questions for each student role	Developed three specific questions for each role to be played by the students

4. Implementation

During the limited field trial stage, an evaluation was conducted to assess students' responses to the SSI-based Student Worksheets. This evaluation aimed to determine the readability and clarity of the developed worksheet. The results of the readability analysis are presented in the following table.

Table 6. Readability test data results

Aspect	Average	% Respond	Category
Design	3,64	91	Very practical
Content	3,56	89	Very practical
Language	3,65	91,25	Very practical
Evaluation	3,12	78	Practical
Attitude	3,56	89	Very practical
Average	**3,51**	**87,68**	**Very practical**

Based on the obtained data, the Socio-Scientific Issue (SSI)-based student worksheets on Green Chemistry within the gold mining context achieved an overall average practicality score of 3.51 (87.68%), achieving the "Very Practical" category. This achievement indicates that the developed learning materials not only meet technical feasibility standards but also effectively facilitate and assist students in the learning process.

The design aspect obtained a high score of 91%, indicating that the visual presentation of the worksheets successfully captured the students' attention. An appealing design, including well-chosen color palettes and proper layouts, constitutes a crucial element in fostering students' reading and learning interest toward the presented material (Fitri et al., 2019). Furthermore, an attractive visual layout can enhance student motivation to complete the tasks provided within the worksheets.

The high score in the content aspect (89%) demonstrates that the integration of socio-scientific issues (SSI) within the context of gold mining successfully created meaningful learning experiences. Utilizing contextual problems that are close to the students' environment (such as the impacts of gold mining) serves as an effective starting point to support student engagement and trigger their critical thinking. This aligns with the principle that learning materials possessing real-life relevance make it easier for students to comprehend abstract scientific concepts (Arsoetar & Sugiman, 2019).

The language aspect recorded the highest score at 91.25%, signifying that the instructions and sentences used in the worksheets were highly communicative and easily understood. The use of clear language is critical to prevent student confusion when executing experimental steps or engaging in discussions (Chotimah & Festiyed, 2021). The success in this aspect ensures that linguistic barriers do not hinder students from constructing their own knowledge (Manoy & Indarasati, 2018).

Although still categorized as "Practical," the evaluation aspect recorded the lowest score (78%) compared to the other components. This finding suggests that the assessment sections or independent tasks may require more detailed and targeted instructions to ensure students do not experience difficulties in communicating their thoughts (Arsoetar & Sugiman, 2019). This score indicates that while students understood the material, the process of providing responses or solving evaluation items still required more intensive teacher guidance.

In addition to the practicality test, the research team also assessed changes in students' attitudes toward

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the environment. The developed attitutude toward environment instrument was administered to students both before and after the learning activities. The resulting data were then analyzed using the descriptive statistical analysis to draw students attitude toward environment after learning process using SSI-based student worksheet. The results of the analysis are presented in Table 6 below.

Table 7. Descriptive statistical analysis result of students' attitude toward environment

Student	Pre-test Score (%)	Criteria	Post-test Score (%)	Category
1	55,00%	Enough	65,00%	Good
2	48,00%	Enough	58,00%	Enough
3	60,00%	Enough	70,00%	Good
4	45,00%	Enough	52,00%	Enough
5	52,00%	Enough	64,00%	Good
6	40,00%	Not enough	50,00%	Enough
7	58,00%	Enough	66,00%	Good
8	63,00%	Good	72,00%	Good
9	50,00%	Enough	62,00%	Enough
10	42,00%	Not enough	55,00%	Enough
11	56,00%	Enough	68,00%	Good
12	46,00%	Enough	58,00%	Enough
13	61,00%	Enough	70,00%	Good
14	44,00%	Enough	54,00%	Enough
15	53,00%	Enough	65,00%	Good
16	38,00%	Not enough	48,00%	Enough
17	57,00%	Enough	67,00%	Good
18	62,50%	Good	71,00%	Good
19	49,00%	Enough	59,00%	Enough
20	51,50%	Enough	63,00%	Good
Average	**51,05%**	**Enough**	**61,70%**	**Enough**

Table 7. Summary of students' attitude toward environment analysis result

Category	Pretest (n)	Pretest (%)	Posttest (n)	Posttest (%)
Very good	0	0%	0	0%
Good	2	10%	11	55%
Enough	15	75%	9	45%
Not enough	3	15%	0	0%
Total	**20**	**100%**	**20**	**100%**

The data analysis reveals that the implementation of SSI-based student worksheets within the gold mining context contributes positively to students' attitudes toward the environment. The descriptive shift from the pretest to the post-test scores demonstrates that integrating socio-scientific issues regarding local small-scale gold mining can trigger students' positive attitudes toward the environment. While the frequency of students in the 'Good' category increased significantly, the overall post-test mean score of students' attitude toward environment (61,70) still remained within the upper boundary of the 'Enough' category, representing a low-level improvement, and eliminated the 'Not enough' attitude category.

When asked about the most beneficial aspects of the worksheet, the majority of students highlighted that the local gold mining context made the chemistry topics highly relatable. Furthermore, students expressed high interest and motivation during the role-playing activities, which allowed them to examine environmental dilemmas from multiple perspectives. Through active discussion and debate, students successfully adopted distinct stakeholder roles, including government officials, local citizens, environmentalists, and gold miners.

3.2. Discussion

The developed SSI-based Student Worksheets address the issues of traditional artisanal gold mining located along the river basin as a socio-scientific issue (SSI) to examine the application of Green Chemistry principles. Given that a significant portion of the students' families are employed in these local gold mines, this topic is expected to foster deeper contextual meaning and personal relevance for the learners. Furthermore, the worksheet utilizes the Problem-Based Learning (PBL) syntax to structure the content and student activities, which are organized into five instructional stages.

In the first stage of the PBL syntax—orienting students to the problem—a real-world case titled 'The Treasures of Borneo' is presented. This case provides contextual information regarding artisanal and small-scale gold mining activities along the river basins of the Gunung Mas Regency. The contextual narrative concludes with a pivotal question: 'In your opinion, is this mining process safe for the miners and the surrounding community?' This open-ended inquiry serves as the focal problem, prompting students to independently articulate the issues they identify, thereby stimulating curiosity and fostering learning motivation rooted in authentic, real-world issues.

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Figure 1. The first stages of the PBL model

In the second stage of PBL—organizing students for study—learners are required to engage in collaborative group activities guided by seven structured focal points. These points are systematically arranged, beginning with understanding the theoretical foundations of Green Chemistry principles and identifying artisanal gold mining practices. This is followed by an analysis of the alignment or discrepancy between these practices and chemical principles, ultimately culminating in the formulation of potential solutions. This structure ensures that team activities remain organized, goal-oriented, and supported by a clear investigative framework, providing a solid foundation for the subsequent inquiry phase.In the third stage of PBL—conducting individual and group investigations—students are presented with a series of investigative questions that require them to actively seek and analyze information from both the provided learning materials and external sources. The investigation phase is divided into two primary focuses. The first focus guides students through theoretical study and comparative analysis, specifically analyzing the 12 Principles of Green Chemistry and identifying the two principles most relevant to artisanal gold mining (Questions 1-3). The second focus involves an in-depth inquiry into current artisanal gold mining practices, supported by contextual information regarding cyanide and mercury. This structure effectively facilitates students' scientific literacy skills in interpreting data and explaining scientific phenomena within the context of artisanal gold mining.

Figure 2. The Fourth Stage of the PBL Model: Developing and Presenting Artifacts Through Student Role-Play

In the fourth stage of PBL—developing and presenting artifacts and exhibits—students are provided with a platform to integrate all their investigative findings. This stage begins with instructions for group discussion presentations and the formulation of conclusions derived from their inquiry activities. A key strength of this SSI-based Student Worksheet lies in the Critical Discussion feature, which is implemented through a role-play activity. Students are not merely presenting facts; they are tasked with adopting one of four distinct socio-scientific roles: (1) Miners, (2) Fishermen/Local Residents, (3) Local Government, or (4) Environmentalists. Each role is equipped with specific guiding questions that must be addressed from that particular stakeholder's perspective—such as addressing health risks from a Miner's viewpoint or formulating policies as the Local Government. This role-play effectively facilitates the enhancement of students' argumentative skills, challenging them to consider Green Chemistry issues through diverse stakeholder perspectives (SSI) and to

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construct arguments supported by chemical evidence as well as social and economic impacts.

The fifth stage of PBL—analyzing and evaluating the problem-solving process—is a crucial phase in the instructional cycle, as it encourages students to engage in metacognition by reflecting on their entire learning journey. Students are prompted to articulate their reflections and suggestions regarding several key aspects: (1) their perspective on the subject matter; (2) their overall impression of the learning activities; (3) their preferences regarding the roles adopted during the role-play; and (4) recommendations for future learning sessions. These evaluative inquiries serve not only as a feedback mechanism for the instructor regarding the effectiveness of the worksheet but also as a means to train students to become self-directed and reflective learners. By reflecting on the process from inception to completion, students are expected to identify their successes and the challenges they encountered while analyzing artisanal gold mining issues through the lens of Green Chemistry.

The high expert validation score (3,60) and excellent student readability rate (87,68) demonstrate that the developed worksheet is both conceptually well structured and practically feasible for classroom instruction. Rather than merely presenting abstract chemical formulas, the worksheet effectively leverages the contextual issue of small-scale gold mining in Gunung Mas Regency. By confronting students with real-world environmental dilemmas—such as mercury contamination, ecosystem degradation, and the economic dependencies of local mining communities—the worksheets successfully moved students from passive learners to active decision-makers. This finding aligns with the core philosophy of SSI-based instruction, which leverages controversial, real-world science issues to stimulate moral reasoning and personal values regarding environmental preservation (Jia & Ren, 2025; Seiter & Fuselier, 2021). These specific elements not only enhanced readability but also significantly stimulated students' engagement with the learning material.

Despite the worksheet's high validity and excellent classroom practicality, the empirical data revealed a contradiction: the overall improvement in students' long-term environmental attitudes remained relatively limited. While the intervention successfully eliminated the 'Not enough' attitude category and pushed a substantial proportion of students into the 'Good' level, it did not boost the transformation toward a 'Very Good' pro-environmental category. This limited improvement demands a critical examination through both a socio-economic and psychological lens.

In the context of Gunung Mas Regency, the community's financial livelihood is intricately bound to local artisanal gold mining operations. When students are asked to embrace green chemistry alternatives that may constrain immediate local economic gains, they experience a form of cognitive dissonance (Kaur & Panda, 2024). They recognize the environmental hazards of mercury pollution, yet they are acutely aware of the economic necessity of mining for their families. Therefore, a short-term instructional intervention—even one that is highly valid and engaging—is fundamentally insufficient to permanently disrupt these deep-rooted socio-economic perspectives.

From a psychological lens, an individual's attitude (*affective domain*) is a deeply rooted psychological construct. Unlike cognitive knowledge, which can be altered rapidly through direct instruction or well-designed worksheets, environmental dispositions are formed over years through cultural habits, parental practices, and socio-economic dependencies (Rocklage & Luttrell, 2021). The worksheet successfully triggered a positive affective paradigm shift and raised baseline awareness. On the other hand, A single course or worksheet, even if socioculturally contextualized, may not be sufficient to address the broader socio-cultural challenges students face (Espinosa & Elipane, 2025; Ramachandran & Singewald, 2026). Socio-economic disparities, such as access to resources and financial constraints, create additional barriers that cannot be mitigated by limited educational tools alone (Matarirano & Muza, 2025). Effective educational strategies require a holistic approach that integrates socio-cultural contexts into the curriculum and pedagogy (Campbell et al., 2025). Therefore, a more prolonged and continuous cross-curricular integration of Green Chemistry is required to foster a 'Very Good' and permanent pro-environmental orientation in students.

These findings are consistent with the study by Rahmawati et al., (2023) , which suggests that implementing SSI-based PBL improves students' attitudes toward the environment by making learning experiences more engaging and relevant . In the context

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of artisanal gold mining, the integration of SSI has been proven to significantly increase students' environmental awareness by bridging abstract chemistry concepts with tangible societal phenomena (Gorito & Morais, 2025; Ramadanty et al., 2025). Furthermore, the use of SSI-based Green Chemistry materials plays a crucial role in strengthening students' environmental arguments, ultimately fostering a deeper understanding of sustainability principles (Prastika & Arianingrum, 2024; Stavans et al., 2019)

4. CONCLUSION

In conclusion, the SSI-based students' worksheet, integrated with Green Chemistry in the context of artisanal gold mining, is highly feasible, as evidenced by a validation score of 3.60 and a strong readability result of 87.68%. The descriptive analysis confirms a positive shift, eliminated the 'Not enough' attitude category and significantly increased the proportion of students achieving a 'Good' pro-environmental categories. This suggests that while the worksheet is an excellent instructional tool, further strategies are needed to more effectively shift students' long-term attitudes toward the environment. By integrating the five stages of Arends' Problem-Based Learning (PBL) framework—ranging from problem orientation to the evaluation of the solving process—the worksheet provides a structured and contextualized learning experience that bridges theoretical chemistry with real-world environmental challenges.

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