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Improving Students' Understanding of Chemistry Concepts and Environmental Sensitivity through the Implementation of the Project-Based Learning (PJBL) Model Based on the Socio-Scientific Issue (SSI) Approach

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ABSTRACT

Increasingly complex environmental problems require education that fosters students' scientific sensitivity and understanding. This study aims to improve students' understanding of chemical concepts and environmental sensitivity through the application of a Project-Based Learning model based on Socio-Scientific Issues. The method used was a quasi-experimental design with a non-equivalent control group, implemented for one semester in Chemistry Education students. The results showed a significant increase in conceptual understanding and environmental awareness. Contextual project-based learning has been proven to integrate science with real social issues. In conclusion, this approach is effective and feasible to be implemented as a transformative learning strategy in higher education.

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INTRODUCTION

Environmental issues are becoming increasingly pressing amidst rapid global development. Issues such as pollution, deforestation, and climate change pose serious threats with widespread impacts on human survival (Caprara & Zimbardo, 2004; Sabri & MacDonald, 2010). Environmental sustainability is therefore closely tied to the collective consciousness of society, especially the younger generation as agents of change. This awareness must be instilled from an early age through an educational process that fosters concern and responsibility for the environment. Education not only transfers knowledge but also shapes character and behavior.

As part of the younger generation, students play a crucial role in addressing environmental challenges. Higher levels of education should be accompanied by increased environmental awareness and sensitivity. However, in practice, many students still show a lack of concern for the environmental issues around them (Haerani et al., 2019). This indicates that the learning approach used is not yet fully effective in fostering caring values. To address this gap, learning strategies must target both the cognitive and affective domains of students.

The Socio-Scientific Issues (SSI) approach provides a learning alternative that connects science, particularly chemistry, with actual and complex social issues (Lusardi et al., 2010). Students are encouraged to understand the relationship between scientific concepts and their real social and environmental impacts. This contextualized learning makes chemistry more meaningful and relevant to everyday life. SSI-based learning also encourages students to think critically, develop social empathy, and make ethical decisions. Thus, the learning process evolves beyond rote memorization into active reflection on real-world phenomena]

Project-Based Learning Model (PjBL) strengthens the effectiveness of the SSI approach through project-based learning experiences. Students are engaged in learning activities that encourage collaborative and contextual problem-solving (Sabri & MacDonald, 2010). In this framework, chemistry concepts are not only understood theoretically but also implemented directly in projects addressing environmental issues. Learning becomes active, challenging, and relevant to students' lives. The projects allow students to experience firsthand the relationship between science and social issues.

The integration of PjBL and SSI creates a holistic and meaningful learning experience. Students not only learn concepts but also engage in finding solutions to real-life problems they identify. Environmentally oriented projects promote the development of 21st-century skills such as critical thinking, collaboration, and creativity (Lusardi et al., 2010). Values of social responsibility and environmental stewardship can be developed through authentic experiences. In this way, learning becomes more than just an academic pursuit it becomes a platform for ethical action and social contribution.

The urgency of this research is increasingly apparent with the growing agenda of sustainable development and the green economy. Students, as future leaders, need a strong ecological awareness to contribute to maintaining the balance of nature. Accordingly, higher education must prepare graduates who are not only scientifically literate but also morally and socially responsible. The implementation of the SSI-based PjBL model is a strategy that aligns with the vision of 21st-century education. This study serves as an innovation in chemistry learning oriented towards sustainability.

This research contributes to the development of a learning model that simultaneously combines the strengths of scientific and social approaches. The use of the SSI-based PjBL model is expected to bridge the gap between theory and practice in chemistry learning. Previous studies have largely explored each approach in isolation, without investigating their integration (Diener, 2000; Lusardi et al., 2010). This research presents a new approach that combines both in a higher education context. The research findings are expected to enrich educational practices and curriculum development.

A mixed methods approach combining quantitative and qualitative methods was used to evaluate the model's impact on students' conceptual understanding and environmental sensitivity. Quantitative data were collected through written tests and attitude scale instruments, while qualitative data were obtained through observations, interviews, and project document analysis. Data triangulation was used to enhance the validity of the research results. This methodological design allows for a comprehensive and rigorous evaluation of both process and outcome.

The learning process involves students in stages of issue identification, concept analysis, solution design, and mini-project implementation. Students are fully involved in all stages to foster a sense of ownership and responsibility for the learning process. Projects are designed based on real-life environmental issues relevant to students' lives. Through direct involvement, students gain a deeper understanding of chemistry concepts while fostering environmental awareness. Project outcomes can also make a tangible contribution to the surrounding community.

Therefore, this study aims to investigate the implementation of the Project-Based Learning (PjBL) model based on the Socio-Scientific Issues (SSI) approach to enhance students’ conceptual understanding and environmental sensitivity. The focus is not only on improving cognitive abilities but also on developing attitudes of caring and responsibility towards the environment. By actively engaging students as learning agents, the study seeks to integrate knowledge and values in a transformative chemistry learning experience. Ultimately, this model contributes to the preparation of graduates who are both scientifically competent and ethically responsible towards the environment.

LITERATURE REVIEW

Higher Order Thinking Skills (HOTS)

Higher Order Thinking Skills (HOTS) encompass critical, creative, reflective, metacognitive, problem-solving, and decision-making skills (Nurhatmanti et al., 2021). These skills are needed in various disciplines, including science, mathematics, language arts, and social sciences (Abdullah et al., 2016; Hasruddin & Lumbabantungkup, 2021; Kamali & Fahim, 2011). Integrating HOTS into learning has been shown to improve students' academic performance, communication skills, and creativity in solving new challenges (Mursyid & Kurniawati, 2019). One key aspect of HOTS is critical thinking, namely the ability to evaluate information, analyze arguments, and formulate rational decisions. Furthermore, creative and reflective thinking plays a role in stimulating new ideas needed in contextual problem-solving (Saputri & Mursid, 2018; Simangunsong et al., 2023; Yanuarto et al., 2021).

The Role of Chemistry Education in HOTS Development

Chemistry education plays a significant role in the development of HOTS because it encompasses many cognitively challenging and applicable concepts. Through a contextual learning approach, chemistry education can strengthen conceptual understanding while enhancing higher-order thinking skills such as analysis, reasoning, and decision-making (Avargil et al., 2011). In the context of sustainability, students need to be equipped with critical thinking skills to assess the impact of chemistry on the environment, as well as problem-solving skills to design solutions (Zoller, 2012). The emphasis on in-depth understanding and exploration of concepts also significantly encourages the development of HOTS (Sharma et al., 2019). Therefore, assessment in chemistry learning should not only assess memorization but also measure students' abilities in logical and analytical thinking (Harta et al., 2020).

Socio-Scientific Issue Approach in Chemistry Education

The Socio-Scientific Issues (SSI) approach has been shown to strengthen the relevance of chemistry education to real life. This approach integrates social, ethical, and environmental issues into science learning, including chemistry, to enhance students' scientific literacy and social awareness (Ismawati & Pertiwi, 2019; Feierabend & Eilks, 2011). SSI enables students to actively engage with current issues such as plastic waste, global warming, or chemicals in food. Learning becomes more engaging because students are asked to evaluate scientific information, develop arguments based on data, and take positions on the issues being studied (Tidemand & Nielsen, 2016). This approach simultaneously develops critical thinking skills, scientific argumentation, and community participation. SSI can also increase learning motivation because the topics raised are close to students' lives (Sadler et al., 2016; Mandler et al., 2012).

Controversial Environmental Issues in the Context of Chemistry

Integrating environmental issues into chemistry education not only improves scientific literacy but also helps students understand the role of chemistry in environmental challenges. The SSI approach can be utilized to introduce controversial issues such as pesticide use, plastic pollution, and climate change (Ke et al., 2021). SSI-based interventions have been shown to be effective in building conceptual understanding and enhancing students' scientific argumentation (Zowada et al., 2018). Some environmental issues relevant to chemistry education include: the impact of pesticides on soil and water; plastic pollution and the potential for microplastics; the contribution of greenhouse gases from industrial chemical processes; and hazardous chemicals in everyday products. Each of these issues encourages students to not only understand the scientific concepts but also to think ethically and socially about their impacts. Chemistry education that is responsive to these issues fosters students' awareness and concern for environmental sustainability and safety.

METHODOLOGY

Research Design

This study used a quasi-experimental design with a non-equivalent control group design. This design consisted of two groups: an experimental group that received learning using the Project-Based Learning (PjBL) model based on the Socio-Scientific Issues (SSI) approach, and a control group that received conventional learning. The purpose of this design was to measure the effectiveness of the SSI-based PjBL learning model in increasing students' environmental sensitivity and understanding of chemical concepts.

Population and Sample

The population in this study was all students of the Chemistry Education Study Program taking Advanced Basic Chemistry in the odd semester of the 2024/2025 academic year. The sample consisted of two classes selected using purposive sampling: one class as the experimental group and one class as the control group. The sample selection took into account the equivalence of the initial characteristics of both classes.

Research Procedures

The research implementation procedure includes four main stages:

a. Preparation

   Researchers developed research instruments, including learning tools, observation sheets, and environmental sensitivity questionnaires. All instruments were tested for validity and reliability by experts.

b. Implementation

   This stage began with a pretest administered to both groups to measure students' initial conceptual understanding and environmental sensitivity. Next, the experimental group implemented the SSI-based PjBL model, while the control group underwent conventional learning. After the intervention, a posttest was administered to both groups to measure changes in learning outcomes.

Additional Data Collection

Qualitative data were collected through active student participation observations, perception questionnaires, and in-depth interviews related to the implementation of the learning model.

Data analysis

1) Quantitative data were analyzed using t-test to determine significant differences between the experimental and control groups.
2) Qualitative data were analyzed descriptively, including the results of observations, interviews, and field notes that provided insight into the learning process and outcomes.

Expected results

This research is expected to produce:

a. Increasing Student Environmental Sensitivity as seen from changes in attitudes and awareness of environmental issues such as pollution and climate change.
b. Improving Understanding of Chemical Concepts through pretest and posttest results, as well as SSI-based project performance.
c. A More Meaningful Learning Experience, namely student involvement in learning that is relevant to the realities of life.

Achievement Indicators

Some of the achievement indicators from this research include:

a. Increasing students' environmental sensitivity as measured through observation, questionnaires and interviews.
b. Improving understanding of chemical concepts through written test instruments and SSI-based project assessments.
c. The level of student participation in all stages of the PjBL project: planning, implementation, and evaluation, as reflected in observations and project reports.

RESEARCH RESULT

Improving Understanding of Chemical Concepts

Based on the pretest and posttest results, there was a significant increase in understanding of chemical concepts in the experimental group. The average pretest score was 60.5, while the posttest score increased to 78.2. The normalized gain (N-gain) calculation resulted in a score of 0.45 (or 44.8%), which is classified as moderate. This suggests that the SSI-based PjBL model is effective in enhancing conceptual grasp, especially by contextualizing abstract chemistry topics through real-world problems.

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The t-test results ($p = 1.122 \times 10^{-5}$) indicated a statistically significant difference between the experimental and control groups, strengthening the conclusion that the improvement was not incidental. This statistical evidence supports the hypothesis that project-based learning enriched with socio-scientific context facilitates deeper comprehension by linking theory with societal application.

Student Environmental Sensitivity

The environmental sensitivity questionnaire revealed positive trends across indicators such as care, responsibility, and awareness, with an average score of 3.39 on a 5-point scale. This score, situated in the moderate-to-high category, reflects a meaningful shift in student attitudes towards environmental concerns.

Student responses highlighted a growing sensitivity to local issues such as water pollution and climate change. Rather than passively learning about these issues, students began actively seeking out and proposing scientific solutions, suggesting an emerging sense of agency and environmental citizenship

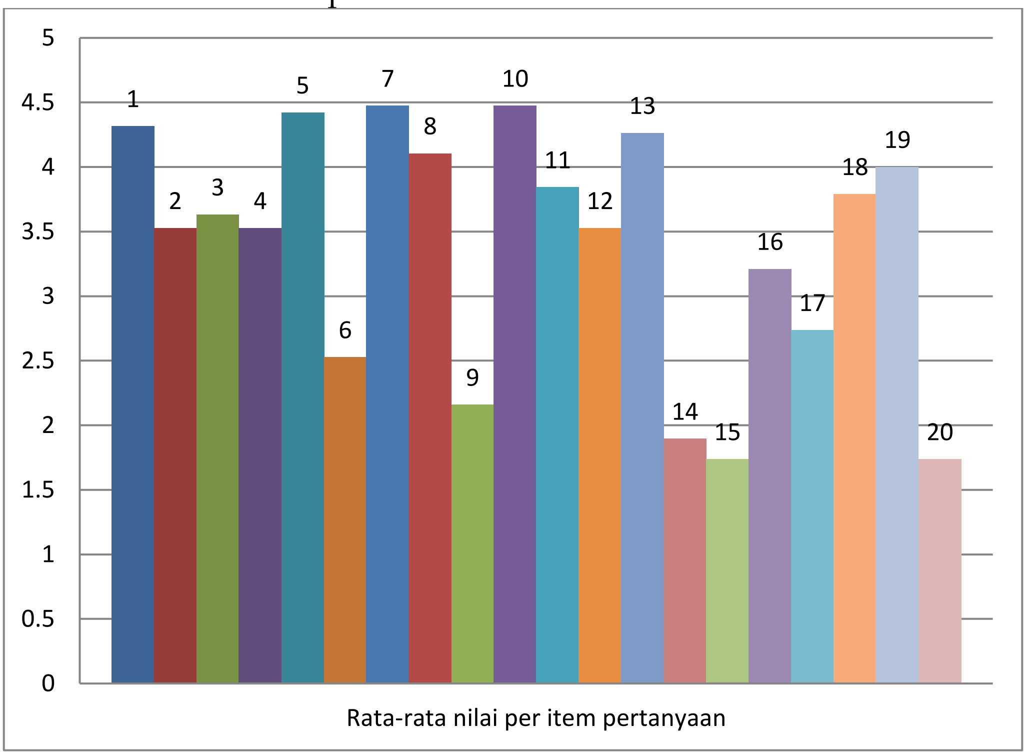

Figure. 1 Student responses to the environmental sensitivity questionnaire

Student Project Performance

Each student developed a research-based project addressing a relevant environmental issue by integrating scientific, social, economic, and ethical perspectives. This multidimensional approach enriched their understanding of how chemistry intersects with real-life problems and societal challenges. While all projects demonstrated student effort and integration of concepts, some stood out for depth and clarity. For instance, the analysis of Citarum River pollution combined data, scientific reasoning, and policy recommendations in a well-structured argument. This project is an example of how students, when given autonomy, can generate impactful and evidence-based proposals**.** Onversely, projects like illegal gold mining showed potential but lacked depth in argumentation and supporting data. This indicates a need for scaffolding and formative feedback to strengthen scientific writing and critical analysis skills in similar future efforts. The project evaluation results are presented in the following table 1:

Table 1. Summary of Student Project Performance

No	Name	Issue Title	Aspects Studied	Conclusion	Score
1	AR	Makassar Beach Reclamation	Economic, Social, Ecological	Impact on coastal ecosystems, need for strict regulations	87
2	BS	Nickel Mine in Sulawesi	Economics, Ethics, Policy	Destroying tropical forests, strict controls are needed	83
3	CD	Plastic Waste in the Ocean	Science, Social, Policy	The need to reduce single-use plastic	90
4	DE	Steam Power Plant vs Renewable Energy	Economics, Ethics, Policy	Renewable energy is more sustainable	85
5	EF	Palm Oil Deforestation	Ecology, Economy, Social	Biodiversity is declining, policy solutions are needed	88
6	FG	Citarum River Pollution	Science, Social, Ethics	Industrial waste has an impact on health	92

7	GH	Pesticides in Agriculture	Science, Social, Ethics	Productivity increases, impacts on land and farmers	80
8	HI	Groundwater Exploitation	Ecology, Social, Policy	Causing a water crisis and land subsidence	84
9	IJ	Global Climate Change	Science, Economics, Policy	Adaptation and mitigation are needed	91
10	JK	Electronic Waste (E-Waste)	Science, Social, Economics	High heavy metal risk, weak recycling	82
11	KL	Biodegradable Plastic	Science, Economics, Ethics	Alternative solution, but expensive	86
12	LM	Kalimantan Forest Fires	Ecology, Social, Economic	Big smoke, need to monitor the land	93
13	M N	Genetic Engineering of Food	Science, Ethics, Policy	Controversial but promising food solution	81
14	NO	PETI (Illegal Gold Mining)	Economic, Social, Ethical	Harming the country and the environment	78
15	OP	Hunting of Endangered Animals	Ecology, Ethics, Social	Threatening biodiversity, education needed	89
16	PQ	Nuclear Energy in Indonesia	Science, Economics, Ethics	Efficient but sparked security controversy	84
17	QR	Urbanization & Green Space	Ecology, Social, Policy	Green urban planning is needed	85

18	Hospital	Microplastics in Drinking Water	Science, Health, Social	New health threat, research needed	85

Observation and Interview Findings

Classroom observations revealed high levels of engagement and collaboration among students in the experimental group. Students displayed increased capacity to argue using scientific data, critically question issues, and relate chemistry concepts to broader social dynamics**.**

Interviews supported this observation students reported greater motivation and enjoyment, noting that the SSI-based PjBL model made learning more meaningful. They felt that their projects had real-world relevance, which not only improved understanding but also deepened their emotional connection to environmental topics.

DISCUSSION

The results of this study reinforce previous findings regarding the effectiveness of the Project-Based Learning (PjBL) model based on the Socio-Scientific Issues (SSI) approach in improving students' understanding of chemical concepts and environmental sensitivity. In line with Sadler et al. (2007), project-based learning in the context of real social issues encourages students' active involvement in connecting chemical theory with phenomena they encounter daily. This makes learning no longer abstract, but contextual and meaningful. Unlike traditional learning that isolates science from societal context, this approach bridges the gap, making chemistry more relatable and impactful.

The application of the SSI approach encourages students to explore various perspectives on environmental issues, from scientific, social, and ethical perspectives. Through this multidimensional lens, students sharpen critical thinking and develop a holistic view of environmental issues. This process hones critical thinking skills and increases students' social sensitivity to the complexity of environmental issues. Investigative and project-based learning, as emphasized by Bell (2010), has been shown to be effective in increasing students' sense of responsibility for their learning process and fostering stronger emotional engagement with the material being studied.

Student involvement in SSI-based projects strengthens scientific literacy, extending beyond conceptual knowledge to awareness of the social impacts of chemical practices on society. Students demonstrate increased critical awareness of issues such as water pollution, plastic waste, and climate change. This is consistent with the principles of environmental literacy-based science education, which emphasizes the relationship between science, technology, and society.

The affective dimension of environmental sensitivity is also reflected in students' attitudes and responsibilities toward the environment. They demonstrate a strong tendency to feel emotionally connected to the environment and recognize the importance of preserving nature. A strong ecological identity forms the basis for consistently developing environmentally friendly behavior. This attitude is crucial for building concrete actions for sustainable environmental conservation in the future.

In terms of environmentally friendly consumption behavior, students demonstrated positive attitudes toward sustainable products and demonstrated confidence in using them. However, while awareness of the importance of green consumption has been established, consistency in practices such as reading product labels or choosing environmentally friendly materials still needs to be strengthened. This suggests that behavioral change takes time and repeated practice to become a habit.

In the context of waste management, the majority of students already have basic habits such as disposing of trash properly and reducing daily waste. However, activities such as sorting and recycling waste are still suboptimal. This finding suggests that although the 3R principles are conceptually understood, their application in daily life still requires additional encouragement and facilitation, particularly in terms of practical application and technical skills.

Student participation in environmental issues has also shown positive results. They are willing to participate in environmental campaigns and activities and actively seek information related to these issues. However, this participation has not yet fully become part of a routine or sustainable movement. This means that while there is concern and interest, strengthening of long-term commitment and collective action is still needed.

Students' confidence in the role of individuals in solving environmental problems is also quite high. They recognize that human behavior, including the use of fossil fuels and industrial waste, significantly contributes to climate change and ecosystem degradation. This confidence that individual actions can have a positive impact demonstrates the potential for developing change agents among students. However, there is still room to deepen their technical understanding of the causal relationship between human activities and environmental degradation.

The projects produced by the students demonstrate their ability to integrate chemical concepts with social, economic, and ethical dimensions. The topics addressed reflect the diversity of contemporary environmental issues and demonstrate the students' ability to analyze issues from multiple perspectives. Issues such as coastal reclamation, nickel mining, plastic waste, and renewable energy provide powerful reflections for students to understand the impact of human decisions on the environment.

One striking finding was the students' success in raising the issue of Citarum River pollution, presented with in-depth and relevant analysis. This project demonstrated that, when given the space to explore, students are able to develop strong arguments and present logical and measurable solutions. Conversely, the project on illegal gold mining still requires strengthening its argumentation and data compilation, indicating the need for further guidance in developing a comprehensive scientific report.

Overall, the student projects demonstrated an integration of theory and practice, science and social values. Students not only understood chemical concepts but also saw their impact on society and the environment. These results demonstrate that the SSI-based PjBL model not only promotes cognitive achievement but also facilitates the holistic development of students' affective and social aspects.

The application of the SSI-based PjBL model in chemistry learning has been shown to shape students' scientific and reflective mindsets regarding social and environmental issues. Students are encouraged to think critically, collaborate, and seek realistic solutions to the global problems they face. This confirms that the integration of projects and social contexts in chemistry education can create learning experiences that are not only meaningful but also transformative.

Overall, the results of this study confirm that the SSI-based PjBL model has strong potential to improve students' scientific competence and social awareness. This model is highly relevant for implementation in chemistry education curricula because it connects theoretical knowledge with real-world practice and fosters a responsible attitude toward the environment. Therefore, it is recommended that a similar approach be more widely integrated into the science learning system in higher education. This signifies that the SSI-based PjBL model goes beyond rote learning by fostering a generation of scientifically literate and socially responsible individuals

The SSI-based PjBL model proves to be a powerful pedagogical strategy, capable of developing scientific competencies while simultaneously fostering environmental and social awareness. It provides a transformative learning experience, preparing students not just as science learners, but as future problem-solvers and ethical decision-makers.

The model’s success suggests its broader applicability in chemistry education curricula. It is recommended that science educators adopt similar integrative approaches to cultivate critical, ethical, and action-oriented learners in higher education.

CONCLUSION AND RECOMMENDATIONS

This study concludes that the Project-Based Learning (PjBL) model based on Socio-Scientific Issues (SSI) is effective in enhancing students’ understanding of chemical concepts and environmental sensitivity by connecting scientific learning with real-world social, economic, and ethical contexts. Students not only showed improved conceptual mastery but also developed stronger critical thinking, collaboration, and environmental responsibility. To optimize its impact, it is recommended that the PjBL-SSI model be integrated into chemistry curricula particularly in courses such as environmental or analytical chemistry accompanied by structured project guidelines and multidimensional assessment rubrics. Instructors should receive targeted training to facilitate interdisciplinary and issue-based learning, while partnerships with local communities or environmental organizations can provide students with authentic contexts for applying their knowledge. These concrete steps will help transform chemistry education into a platform for building scientifically literate and socially responsible graduates.

FURTHER RESEARCH

This study has limitations in that the sample size was limited to two classes from one study program, so generalization of the results requires caution. Furthermore, the implementation of the SSI-based PjBL model was short-term, thus not reflecting the long-term impact on student behavior change. Therefore, it is recommended that future research involve a broader and more diverse sample, employ a longitudinal design, and explore the integration of this approach in other science courses to measure effectiveness across learning contexts.

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