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Green Project Chemistry Based Learning Model to Enhance Scientific Literacy And Sustainability Awareness In Education

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Abstract

Green chemistry education has become a significant approach in improving students' scientific literacy and sustainability awareness. This study examines the application of project-based learning (PjBL) model in the context of green chemistry as an innovative method to strengthen students' understanding of sustainability principles. Through literature review from various scientific sources, this study shows that the integration of PjBL in green chemistry learning can improve students' critical thinking, collaboration, and communication skills. In addition, project-based learning allows students to engage in more environmentally friendly experiments, such as the development of biodegradable materials and chemical waste management strategies. However, the implementation of this method still faces challenges, such as limited understanding of educators about green chemistry, lack of resources, and suboptimal integration into the curriculum. Therefore, intensive training is needed for educators, provision of comprehensive learning materials, and utilization of technology as a tool. With the right support, the implementation of this model can produce a generation that is more environmentally aware and able to provide solutions to global sustainability challenges.

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1. INTRODUCTION

Green chemistry education has become one of the significant approaches in supporting sustainability and improving students' scientific literacy. Green chemistry focuses on developing environmentally friendly chemical processes and products, with the aim of reducing negative impacts on ecosystems and human health. This approach is not only relevant in the educational context, but also an important strategy to support the achievement of Sustainable Development Goals (SDGs) through

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integrating sustainability principles into the educational curriculum (Sari & Atun, 2023; Dewi & Listyarini, 2022). The project-based learning (PjBL) model has proven effective in encouraging students to understand green chemistry concepts in depth while developing critical thinking, collaboration, and communication skills. Research shows that the application of PjBL integrated with green chemistry can improve the critical thinking skills of high school students, especially in materials such as chemical equilibrium (Rahma et al., 2024). In addition, this approach allows students to be directly involved in practical projects such as the development of biodegradable materials or experiments that minimize chemical waste (Sholahudin et al., 2024). The development of green chemistry-based teaching materials also contributes greatly to improving students' scientific literacy and environmental awareness. Green chemistry-based practicum modules designed for high school level have successfully improved students' understanding of environmental issues through experiments relevant to everyday life (Dewi & Listyarini, 2022). At the higher education level, project-based online learning programs such as summer courses are able to increase the involvement of chemistry teacher candidates in sustainability issues, so that they are better prepared to integrate these concepts in future learning practices (Paristiowati et al., 2022).

In addition, technology-based approaches have also been used to support green chemistry learning. The development of the Chemsdro application as a learning media based on Education for Sustainable Development (ESD) at the junior high school level shows its effectiveness in improving students' understanding of sustainability principles through chemical reaction materials (Fibonacci et al., 2020). This shows that technology integration can be a powerful tool to support sustainability education.

Collaborative and interdisciplinary learning also plays an important role in green chemistry education. Methods such as problem-based learning (PBL) and guided inquiry have been widely used to help students understand the principles of green chemistry while developing systematic and reflective thinking skills. These approaches encourage students to actively participate in real problem solving related to global sustainability challenges (Hardianti & Wusqo, 2020; Vogelzang et al., 2020). This research aims to further explore how a project-based learning model integrated with green chemistry concepts can improve students' scientific literacy and sustainability awareness. With various innovations that have been developed, this approach is expected to make a significant contribution to the development of a young generation that is environmentally conscious and able to provide solutions to global challenges related to sustainability.

2. MATERIALS AND METHODS

This study uses a literature study method to review various relevant sources regarding the project-based learning model in the context of green chemistry and its impact on scientific literacy and sustainable awareness. The sources used are scientific articles from leading journals that are systematically selected and relevant to the topics discussed. In the selection of journals, the criteria used include topic relevance,

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methodological quality, and contribution to understanding the application of project-based learning models in chemistry education. A total of ten journals were selected to provide a comprehensive view of the application of project-based learning models in green chemistry learning, which aims to improve scientific literacy and sustainable awareness. The literature collection process was carried out by searching for journals that contain discussions related to the concepts of green chemistry, scientific literacy, and sustainable awareness in education, as well as project-based learning models that have been applied in various educational contexts. The analysis process was carried out by compiling and organizing the findings from the selected journals, then identifying patterns and similarities from various existing studies, and evaluating the effectiveness of the learning model in improving students' understanding of green chemistry and sustainable issues. The data obtained from this literature study were then analyzed descriptively by exploring pedagogical implications and their benefits for the development of more sustainable education.

3. RESULTS AND DISCUSSION

Through a comprehensive review of ten related scientific journals, the transformative potential of project-based learning (PBL) models within a green chemistry framework has been demonstrated. Key findings suggest that PBL not only enhances students' scientific literacy but also fosters a deep and lasting awareness. However, the implementation of this pedagogical model is fraught with challenges. A significant barrier is educators' inadequate understanding of the principles underlying green chemistry and the methodologies for their integration into educational curricula. The suggested remedies underline the importance of ongoing training and professional development for educators, including workshops, seminars, and access to digital educational resources. The creation of rich and relevant educational materials, including clear instructional resources, safe and environmentally friendly experiments, in addition to the incorporation of digital technologies for interactive learning, are also essential for success.

Furthermore, the study underlines the difficulties associated with the adoption of innovative pedagogical strategies such as PBL and Scrum, particularly regarding students' lack of experience with collaborative and project-centric methodologies. The proposed interventions advocate providing intensive training and mentoring for educators and learners, starting with small, manageable projects, and leveraging local technologies and resources to mitigate constraints related to resource availability. Furthermore, the formulation of a comprehensive assessment instrument, which encompasses multiple dimensions of scientific literacy, such as theoretical knowledge, practical competencies, and critical thinking capacity, emerged as an important solution to address the shortcomings in evaluating students' scientific literacy skills.

Another important finding relates to the inadequate integration of sustainability in chemistry education curricula. The investigation advocates the formulation of curricula that systematically embed the

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principles of green chemistry and sustainability, alongside the provision of comprehensive teacher training to effectively embed these concepts. Furthermore, collaboration with industry and research institutions is essential to provide relevant resources and insights. Finally, the study describes disparities in access to and utilization of learning technologies as additional barriers to the implementation of project-based learning (PBL). Proposed solutions include increased collaboration between government entities, the private sector, and educational institutions to ensure equitable provision of technological devices and internet access, as well as the formulation of hybrid learning models that combine technological and non-technological methodologies.

Further examination of the reviewed literature suggests that project-based learning (PBL) facilitates the development of critical thinking, problem-solving, and collaborative skills among students through authentic and meaningful learning experiences. Students not only assimilate green chemistry principles but also apply these principles to real-world projects that relate to everyday life and global environmental dilemmas. For example, initiatives centered on the creation of sustainable green products, waste management strategies, or renewable energy solutions can offer an immersive educational experience and equip students to develop into responsible and sustainable citizens.

Furthermore, this study underscores the importance of a comprehensive approach to formative and summative assessment in the context of PJBL. Assessment should not only concentrate on the final outcome of the project but also encompass students' learning trajectories, including engagement, collaboration, and reflective practice. Competency-based assessment frameworks, portfolios, and peer evaluations can be used to provide constructive feedback and to monitor improvements in students' scientific literacy competencies and sustainability awareness.

In summary, the findings obtained from this literature review confirm that PJBL serves as an efficacious pedagogical approach to enhance students' scientific literacy and foster sustainability awareness in relation to green chemistry. However, its successful implementation requires careful planning, strong support from diverse stakeholders, and ongoing evaluation. By addressing existing challenges and actualizing proposed solutions, PJBL has the potential to develop into a transformative educational model and contribute to a more sustainable and environmentally responsible educational paradigm.

4. CONCLUSIONS

The conclusion of this study shows that the implementation of project-based learning (PjBL) integrated with the concept of green chemistry has significant potential in enhancing scientific literacy and students' awareness of sustainability. This learning approach allows students to develop critical thinking, collaborative, and practical skills through authentic learning experiences that are relevant to global environmental issues. However, to achieve successful implementation, a deep understanding of green

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chemistry principles by educators is required, along with ongoing training and professional development support. Challenges such as limited resources and understanding of the methodology can be addressed through intensive training, the use of educational technology, and collaboration with industry and research institutions. Furthermore, it is essential to develop a systematic curriculum that embeds the principles of sustainability and green chemistry, as well as creating comprehensive assessment tools. With careful planning and appropriate support, PjBL can be an effective pedagogical approach in creating a generation that is more environmentally conscious and ready to provide solutions to global sustainability challenges.

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