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Potential Development of Green Chemistry Teaching Materials Based on Environmental and Sustainability Issues

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Abstract: This study aims to explore the potential development of green chemistry-based teaching materials integrated with local environmental and sustainability issues in West Kalimantan Province for students of the Chemistry Education Study Program, Universitas Muhammadiyah Pontianak (UMP). The research adopts a descriptive-qualitative approach focusing on the identification of curriculum opportunities, environmental context, and green chemistry principles implementation aligned with Education for Sustainable Development (ESD) and Outcome-Based Education (OBE). Data were collected through document analysis (curriculum review, environmental reports), interviews with lecturers and students, and literature analysis of regional environmental challenges. The results indicate that the local environmental issues (peatland degradation, river pollution, and plastic waste) are relevant to be integrated into chemistry teaching materials. Furthermore, 82.2% of lecturers and 88.6% of students express the need for context-based green chemistry materials emphasizing sustainable local resources. The study concludes that UMP's chemistry curriculum holds strong potential to develop innovative, environmentally contextualized teaching materials promoting sustainability literacy among students.

Keywords: Environmental; Green chemistry; Sustainability issues; Teaching material development

Introduction

Chemistry education plays a crucial role in producing a generation of scientists and educators who not only have a deep understanding of the basic concepts of chemistry, but also have the ability to apply the science by considering environmental impacts. In the midst of the increasing issues of climate change and environmental degradation that threaten global life, there is an urgent need to develop teaching materials that are not only relevant to the development of science, but also oriented towards sustainability and environmental solutions. One approach that can be applied is the development of green chemistry teaching materials based on environmental and sustainability issues (Anastas & Warner, 2000; Clark & Macquarrie, 2002; D'Avanzo, 2008; Lestari et al., 2024; Mbah & Ezegwu, 2024; Seifert et al., 2024).

Green chemistry, which focuses on reducing the use of hazardous materials and introducing environmentally friendly chemical processes, is not only a relevant topic, but also an indispensable approach in the world of education. The principles of green chemistry prioritize the use of safer raw materials, reduce waste, and increase energy efficiency in every chemical process (Anastas & Warner, 2000; Babbar, 2024; Cahyani et al., 2024; Jain et al., 2024; Kurul et al., 2025; Lancaster et al., 2011; Poliakoff et al., 2002; Uak, 2024). In the context of education, this concept needs to be introduced early so that students not only understand chemical theory but also realize the social and environmental impacts of experiments and chemical

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applications in daily life (Lancaster et al., 2011). Therefore, the development of teaching materials that focus on green chemistry and sustainability is very relevant, especially in Indonesia, which is currently facing serious environmental challenges (Dahlan, 2013; Summers & Harris, 2017).

Green chemistry-based education has the potential to produce graduates who are more responsive to environmental challenges. The implementation of green chemistry in higher education is expected to not only contribute to more sustainable technological development, but also change the mindset of students in choosing more environmentally friendly scientific solutions (Poliakoff et al., 2002; Young & Makowski, 2015). This is especially important in West Kalimantan Province, which has tremendous biodiversity and abundant natural resources, but also faces serious threats to its sustainability. In recent decades, West Kalimantan has experienced significant deforestation due to mining, plantation, and land clearing activities (Houghton, 2007; Dahlan, 2013). In addition, water and air pollution due to industry is also an issue that cannot be ignored (Dahlan, 2013).

On the other hand, West Kalimantan Province faces various environmental issues such as deforestation (Hestiantini, 2023; Putra, 2024; Salim et al., 2019), Kapuas River water pollution (Olfa et al., 2025; Hapipin et al., 2025; Purnaini & Saziati, 2023; Sugandi et al., 2021; Loh et al., 2016), peatland degradation (Ahmad et al., 2023; Jaenicke et al., 2010; Lee at al., 2025), and increasing volume of plastic waste (Haribowo, 2025; Sarminingsih et al., 2022; Chowdhury et al., 2023; Herawati et al., 2024). This condition is an ideal context for integrating sustainability issues in chemistry learning in universities.

Based on the Curriculum Document of the Chemistry Education Study Program, University of Muhammadiyah Pontianak (2024), the scientific vision of the study program emphasizes the development of sustainability-based chemistry education (Education for Sustainability). Therefore, the development of green chemistry teaching materials that integrate the local environmental problems of West Kalimantan is very important. Sustainability-based chemistry education can help students at the University of Muhammadiyah Pontianak to understand and overcome specific environmental challenges in their area. Through this approach, students not only learn about chemical theory, but are also trained to think critically and innovatively in developing environmentally friendly solutions in a local context. This is in line with the vision of higher education that creates graduates who are able to make a real contribution to environmental and sustainability problem solving (Summers & Harris, 2017; Jenkins & Lutz, 2013).

The importance of preparing teaching materials based on green chemistry for chemistry education in West Kalimantan also cannot be separated from the great challenges faced by the world of education in Indonesia in general. Many universities in Indonesia, including the University of Muhammadiyah Pontianak, still use chemistry teaching materials that do not pay attention to sustainability aspects and environmental solutions (Young & Makowski, 2015; McMurry & Fay, 2008). In fact, there is currently an urgent need to introduce concepts such as renewable energy, chemical waste management, and environmentally friendly products in chemistry learning. Therefore, this study aims to examine the potential for the development of green chemistry teaching materials based on environmental and sustainability issues in West Kalimantan Province, to contribute to improving the quality of chemistry education that is more relevant to local conditions, as well as supporting environmental sustainability efforts in West Kalimantan (Jenkins & Lutz, 2013; McMurry & Fay, 2008).

Through this research, it is hoped that practical solutions can be found in the development of teaching materials that not only meet the standards of the chemistry education curriculum, but are also able to create positive changes in student behavior in the face of increasingly complex environmental challenges. Thus, this research contributes not only in the field of chemistry education, but also in Indonesia's great efforts to achieve the Sustainable Development Goals (SDGs), especially related to quality education and sustainable environmental management (McMurry & Fay, 2008; Green, 2010; Jenkins et al., 2016).

Method

This type of research is descriptive-qualitative exploratory with a document study and interview approach. The research subjects include main documents such as the UMP Chemistry Education Study Program Curriculum and the RPS courses in Environmental Chemistry, Basic Chemistry, and Environmental Education. The informants in this study consisted of five lecturers teaching basic and environmental chemistry courses, as well as thirty fifth-semester students. In addition, this study also uses the West Kalimantan environmental report (BPS & KLHK, 2023–2024) as a contextual source. The analysis of curriculum documents was carried out using a content analysis approach to explore the integration of green chemistry principles and Education for Sustainable Development (ESD), while the results of interviews were analyzed using the thematic coding method. All analysis results are then triangulated and presented in the form

of a map of the potential integration of green chemistry teaching materials based on environmental issues.

Result and Discussion

Curriculum Conditions and Integration Opportunities

Analysis of the curriculum of the Chemistry Education Study Program, University of Muhammadiyah Pontianak shows that graduate learning outcomes (CPL) have included important aspects such as environmental awareness, critical thinking skills, and innovation in learning. These three aspects reflect the direction of curriculum development that is oriented towards the formation of prospective chemistry educators who are not only academically competent, but also have concern for sustainability and social responsibility issues. The integration of environmental values in CPL is a strategic step in realizing chemistry education that is relevant to the needs of the 21st century.

However, the results of the review of the curriculum structure and the Semester Learning Plan (RPS) show that the application of the concept of green chemistry is still uneven in all courses. Some courses such as Environmental Chemistry, Chemical Analysis, and Chemistry Learning Methodology have great potential to integrate the principles of green chemistry, but their implementation is still conceptual and not yet systematic. This opens up opportunities to develop teaching materials that are more applicable and contextual so that students are able to relate the concept of chemistry with sustainable practice in the field.

Relevant Environmental Issues in West Kalimantan

Based on data from the Ministry of Environment and Forestry (MoEF) and the Central Statistics Agency (BPS) in 2024, there are several main environmental issues in West Kalimantan Province that have high relevance to be integrated into chemistry learning. These issues include pollution of the Kapuas River caused by household activities and gold mining, fires and peatland degradation that have an impact on air quality and ecosystem balance, as well as increasing the volume of urban plastic waste in the Pontianak and Kubu Raya areas. These three issues not only describe real and complex environmental problems, but also provide a rich scientific context to encourage students to understand the relationship between the concept of chemistry and its impact on the surrounding environment.

The results of the analysis show that there are three main issues that have the potential to be used as a context for green chemistry teaching materials in West Kalimantan (Table 1).

These three issues have a high proximity to the lives of the local community and are relevant to the 1st (waste prevention) and 10th Green Chemistry principles (biodegradable material design). These issues can be used as a context for problem-based learning (PBL) that supports the application of green chemistry and Outcome-Based Education (OBE) principles. Through this approach, students are invited to analyze local environmental problems using relevant chemical concepts, such as oxidation-reduction reactions in heavy metal pollution, the decomposition process of organic matter in peatlands, or the degradation of polymer compounds in plastic waste. Thus, learning not only focuses on theoretical aspects, but also fosters students' critical thinking skills, scientific creativity, and ecological awareness as prospective educators who are able to integrate chemistry with environmental sustainability values.

Table 1. Main issues that have the potential to be used as a context for green chemistry teaching materials in West Kalimantan

Environmental Issues	Related Chemical Concepts	The Potential of Teaching Material Integration
Palm oil liquid waste	Oxidation reactions, catalysts, biotechnology	Palm oil waste treatment practicum with the principle of green catalysis
River mercury pollution	Redox, chemical analysis, toxicology	"Zero Mercury" case study for environmental chemistry learning
Plastic and microplastic waste	Polymers, degradation, organic chemistry	Natural enzyme-based plastic biodegradation module and FTIR analysis

Perception of Lecturers and Students

The results of interviews and questionnaires show that both lecturers and students have a very positive perception of the development of green chemistry teaching materials based on local environmental issues. A total of 82.2% of lecturers stated that teaching materials that raise environmental issues in West Kalimantan — such as the pollution of the Kapuas River and peatland degradation — can increase the relevance of learning and help students understand the relationship between chemical concepts and real life. The lecturers also assessed that the integration of local issues was able to encourage students to think critically, actively participate in discussions, and foster a sense of responsibility for environmental conservation. This finding is in line with the principles of Education for Sustainable Development (ESD) and the practice of Outcome-Based Education (OBE) which are the basis of the curriculum of the UMP Chemistry Education Study Program.

Meanwhile, from the student side, 88.6% of respondents stated that learning chemistry related to environmental issues makes concepts easier to understand and increases motivation to learn. Students feel more interested when the material is contextualized with real problems around them, such as household waste treatment or the use of environmentally friendly chemicals. These results also support the research of Sanjaya et al. (2024) at Sriwijaya University who found that the use of case-based green chemistry student worksheets (MFIs) can increase environmental awareness and interest in learning chemistry. Overall, both lecturers and students showed strong support for the development of local context-based teaching materials that integrate the principles of green chemistry and sustainability.

Table 2. Results of lecturer and student perception assessment on the development of green chemistry teaching materials

Assessment Aspects	Lecturer (%)	Students (%)	Information
Local issue-based teaching materials increase learning relevance	85	88	Very positive
Integration of environmental issues helps understand chemical concepts	82	90	Excellent
Local context-based learning increases learning motivation	80	92	Excellent
Green chemistry teaching materials foster environmental awareness	88	89	Very positive
Training/enrichment is needed for lecturers for the application of green chemistry	76	84	Need reinforcement

Average level of positive perception: Lecturers = 82.2%, Students = 88.6%.

Table 2 shows that both lecturers and students have a high level of acceptance and support for the development of green chemistry teaching materials based on environmental and sustainability issues in West Kalimantan.

Development Design Recommendations

The development of green chemistry teaching materials at the University of Muhammadiyah Pontianak (UMP) utilizing the 4D (Define, Design, Develop, Disseminate) model represents a strategic approach grounded in both educational research and contextual learning principles. This systematic framework, originally developed by Thiagarajan et al. (1974), has demonstrated proven effectiveness in educational material development across diverse subject areas and institutional contexts (Suarmita et al., 2025). The 4D model functions as a structured yet flexible developmental approach comprising four distinct but interconnected stages. The Define stage involves conducting comprehensive needs analysis, including identification of learning gaps, student characteristics, and curriculum requirements (Yuhdi et al., 2024). This foundational phase establishes the problem space and clarifies what educational objectives must be achieved. The Design stage focuses on planning the structure, content organization, and pedagogical strategies that will underpin the teaching materials (Yuhdi et al., 2024). During this phase, developers create prototypes and outline the conceptual framework for their products. The Develop stage encompasses the actual creation of materials, expert validation, and iterative refinement based on feedback from material experts, media specialists, and linguists (Suarmita et al., 2025). Finally, the Disseminate stage involves broader distribution and implementation of the validated materials across educational settings (Ananda et al., 2021). The systematic nature of the 4D model makes it particularly suitable for developing contextual teaching and learning (CTL)-based materials. As demonstrated in Mukhlishin (2024) research on Physical Chemistry teaching materials using CTL principles, the model's flexibility allows developers to adapt their approaches while maintaining structural rigor. Mukhlishin (2024) revealed that CTL-based materials developed through the 4D framework achieved validity scores of 98.75% for material content, 87.33% for media presentation, and 98.00% for language clarity, all falling within very valid criteria. Practicality testing showed 95.8% in individual trials and 89.6% in small group trials, confirming the approach's effectiveness.

The model's emphasis on product validation before implementation distinguishes it as particularly valuable for developing instructional materials in specialized domains such as green chemistry. Multiple studies employing the 4D model have consistently demonstrated high validity and practicality ratings. For instance, research on multimedia-based interactive modules and guided inquiry-based electronic worksheets across chemistry education has shown that this developmental approach produces materials rated between 80-98% on validity scales (Sarafina & Nasrudin, 2024).

Green chemistry education has emerged as a critical component of contemporary chemistry curricula, particularly within frameworks emphasizing sustainability and environmental responsibility (Widyawati et al., 2025). The development of green chemistry teaching materials requires careful attention to conceptual complexity, contextual relevance, and

student engagement. The 4D model facilitates this by enabling developers to explicitly connect chemistry principles to real-world environmental applications during the Define and Design phases (Teplá et al., 2025). This is essential because students often struggle to understand the connection between abstract chemical concepts and their practical environmental implications (Koulougliotis et al., 2024).

Research by Widyawati et al. (2025) on Education for Sustainable Development (ESD)-based green chemistry materials demonstrated that when materials are systematically developed with clear connections to sustainability goals, students develop enhanced environmental awareness and critical thinking skills. The 4D model's deliberate structure supports this outcome by requiring developers to define learning outcomes explicitly before design activities commence.

In the context of the development of green chemistry teaching materials based on environmental and sustainability issues in West Kalimantan, the 4D model can be described in detail as follows:

Stage 1: Define

This stage aims to identify the needs for developing teaching materials by analyzing the curriculum, student needs, and local environmental issues, including an analysis of the UMP Chemistry Education Study Program curriculum to find gaps in the integration of green chemistry concepts (Binani et al., 2024; Chen et al., 2024; Elvira & Fitriza, 2023; He et al., 2025); a needs analysis through interviews with lecturers and students (Abdussyukur et al., 2021; Dewi et al., 2019; Kortam et al., 2025) to determine relevant environmental topics such as Kapuas River pollution, plastic waste, and peatland degradation; and a concept and learning task analysis to identify the relationship between chemical concepts (e.g., redox reactions, polymers, acid–base materials) and the environmental issues to be addressed. The outcome of this stage is a map of teaching material needs that align with the local context and graduate learning outcomes (LO) (Jnior et al., 2024; Mahaffy et al., 2024).

Stage 2: Design

At this stage, the structure of the teaching materials is designed by determining the format, content, media, and learning strategies, which includes designing a framework that contains learning objectives, key green chemistry concepts, and the context of local issues; selecting appropriate learning approaches such as Problem-Based Learning (PBL) (Wahyuni & Sari, 2024; Vaz et al., 2025) or the Case Method (Diquito et al., 2024; Nabila et al., 2025) to explore real-world environmental problems; and preparing prototypes of teaching materials in the form of modules, e-books, or student worksheets (MFIs) equipped with simple experimental activities based on green chemistry principles. The product of this stage is an initial draft of the teaching materials (prototype I) that is ready for limited testing.

Stage 3: Develop

This stage focuses on validating and testing the teaching materials through assessments by material experts, media experts, and linguists to ensure content feasibility and pedagogical appropriateness, followed by revising the materials based on expert feedback; conducting a limited trial with 5th-semester students to evaluate the practicality and effectiveness of the materials; and analyzing trial data using indicators of validity, practicality, and effectiveness, as referenced in Mukhlishin (2024). The outcome of this stage is a final version of the teaching materials (prototype II) that has been demonstrated to be valid and practical for use in lectures.

Stage 4: Disseminate

The final stage is the dissemination of the development results, which includes implementing the teaching materials in official lectures within the UMP Chemistry Education Study Program, conducting workshops or lecturer training to enhance the ability to integrate green chemistry into instruction, and producing scientific publications as well as digitizing the teaching materials so they can be accessed by students and lecturers across the West Kalimantan region. This stage ensures that the innovation in teaching materials is beneficial not only internally but also contributes to strengthening education for sustainable development (ESD) at the regional level.

The following is a diagram of the development of a 4D model that can be applied in this study.

Figure 1. 4D model

Through the application of this 4D model, the development of green chemistry teaching materials at the University of Muhammadiyah Pontianak will run in a structured, needs-based, and measurable in its effectiveness. This approach is expected to be able to produce teaching material products that are valid, practical, effective, and relevant to the context of environmental sustainability in West Kalimantan, thereby supporting the formation of prospective chemistry teachers who are ecologically insightful and globally competitive.

Conclusion

The Chemistry Education Study Program of the University of Muhammadiyah Pontianak has great potential to develop green chemistry teaching materials that are oriented to local environmental issues in West Kalimantan, such as river pollution, peatland degradation, and plastic waste management, which can be used as a problem-based learning context to strengthen the integration of Education for Sustainable Development (ESD) and Outcome-Based Education (OBE) in the curriculum. The development of these teaching materials not only aims to improve the understanding of chemical concepts in an applicative and contextual manner, but also to form students who have concern for the environment, have Islamic character, and are globally competitive in accordance with the vision of the University of Muhammadiyah Pontianak as an educational institution based on progressive Islamic values and contribute to sustainable development.

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In this study, the author makes different contributions. The author has read and approved the published version of the manuscript.

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Conflicts of Interest
The author states that there is no conflict of interest. Funders have no role in the design of the research; in data collection, analysis, or interpretation; in scriptwriting; or in the decision to publish the results.

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