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DEVELOPMENT OF A GREEN CHEMISTRY MODULE BASED ON PROJECT-BASED LEARNING

Anggi Ristiyana Puspita Sari*, Ruli Meiliawati, Suandi Sidauruk, Agtri Wulandari, Fatchiyatun Ni'mah, Berta Uli Handayani, Florens Br Siringo-ringo
Chemistry Education, Universitas Palangka Raya
Jl. Yos Sudarso, Palangka Raya 74874, Kalimantan Tengah, Indonesia
*correspondent author: anggi.ristiyana@fkip.upr.ac.id

Abstract. The Sustainable Development Goals (SDGs) present new challenges in global competition. This has been reflected in the Merdeka Curriculum, which incorporates green chemistry materials and project-based learning models. However, the lack of project-based learning module has become a significant obstacle in implementing this curriculum in schools. This research aims to determine the quality of the green chemsitry module that was developed. The product development follows the ADDIE model, though the research only covers the development stage. The initial product was reviewed by 6 experts to assess its quality. A Likert-scale questionnaire was used as the evaluation instrument, consisting of four components with a total of 33 statements. Meanwhile, the user response instrument consisted of 12 statements. The results showed that the project-based green chemistry module was deemed feasible for implementation in learning. This was evidenced by the ideal percentage from the product feasibility assessment by experts at 95.95%, which falls into the Very Good category. Furthermore, the small-scale trial results indicated an ideal percentage of 82.58% categorized as Good. This module supports the implementation of SDGs in reducing environmental pollution, as it includes several projects that students can apply in waste management.

Keywords: green chemistry, learning module, project-based learning

INTRODUCTION

Sustainable Development Goals (SDGs) are global goals set by the United Nations (UN) as part of the world's development agenda to achieve a better and more sustainable future for all (Chien & Knoble, 2024). These goals are interrelated and cover various aspects of life, from poverty alleviation, health, education, gender equality, to environmental protection. This concept requires a response from the education sector, which plays a crucial role.

Education is the key to achieving SDGs. Education is responsible for shaping individuals who are aware of global issues, possess the skills to solve complex problems, and are committed to creating a better world (Holmes et al., 2022). By providing quality and relevant education, we can nurture generations with the knowledge, skills, and values needed to build a better world for everyone. One way to implement SDGs in learning activities is by integrating SDGs values into the curriculum, implementing active problem-based learning, making SDGs values a theme across subjects, or developing learning modules (Alfathy et al., 2024).

Green chemistry learning is one way to realize SDGs through education. The green chemistry topic offers solutions to reduce the negative impact of the chemical industry on the environment, and education plays a vital role in spreading the

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knowledge and skills needed to implement the principles of green chemistry (Zimmerman et al., 2020). This becomes crucial as awareness of environmental damage grows and the need to transition to more sustainable practices increases (Ivanković et al., 2017; Marques et al., 2020). One tangible example of the education sector responding to this phenomenon is the inclusion of green chemistry topics and project-based learning in the Merdeka Curriculum.

Changes in the direction of learning activities in the Merdeka Curriculum require innovations to help educators implement classroom learning. This is crucial because the learning approach used in chemistry education often fails to engage students and equip them with the necessary skills to apply green chemistry in real life (Driel et al., 2002). The learning approaches commonly used focus on memorization and theory and provide limited opportunities for students to conduct experiments, solve problems, and collaborate (Kokotsaki et al., 2016; Martinez, 2022).

The project-based learning (PjBL) model has been shown to be effective in improving students' interest, motivation, and learning outcomes (Atta & Alghamdi, 2018). PjBL encourages students to learn actively and independently through investigation, problem-solving, and presentation. PjBL helps students develop 21st-century skills, such as critical thinking, communication, and collaboration (Kokotsaki et al., 2016). According to research, the potential of project-based learning can also enhance learning motivation, skills in managing learning resources, communication ability, foster responsibility and cooperation among students, and boost creativity and independence (Akbar & Bahri, 2017).

On the other hand, learning resources that support green chemistry education are still limited. Modules, as one type of learning resource, are materials that are systematically and attractively arranged, allowing students to study them independently (Simangunsong & Pane, 2021). Modules help students understand concepts and materials, develop procedures, and apply these concepts, procedures, and principles to solve problems (Lia et al., 2016). Research on the development of project-based modules in the context of green chemistry is also limited, presenting a challenge for educators in implementing classroom learning.

Further research is needed to develop effective and engaging modules that can help students understand and apply the principles of green chemistry. In this context, project-based modules have high urgency for several reasons, as outlined by the Ministry of Education, Culture, Research, and Technology (Kementerian Pendidikan Kebudayaan Riset dan Teknologi, 2021): 1) Project-based modules align with the philosophy of the Merdeka Curriculum, which emphasizes active, creative, and contextual learning; 2) They provide practical guidance for teachers in designing student-centered learning by offering project steps, selecting relevant and contextual projects based on students' needs and interests, and assessing students' learning outcomes with clear evaluation rubrics; 3) They improve students' understanding of the concepts learned, develop critical and creative thinking skills to solve problems, strengthen cooperation and communication among students in group projects; 4) They help students develop skills needed for real-world work, become independent and adaptive learners who can adjust to changes, and contribute to solving global problems like climate change and environmental damage. Based on the problems outlined, this study aims to produce a project-based module on green chemistry.

RESEARCH METHOD

This research is a type of research and development (R&D) aimed at producing a product and testing its feasibility (Aldoobie, 2015). This research adapts the ADDIE development model. The ADDIE model is a learning design method developed by Dick & Carry, consisting of five stages: analysis, design, development, implementation, and evaluation. However, this study only covers the procedures up to the development stage. The stages of the ADDIE model performed can be seen in Figure 1.

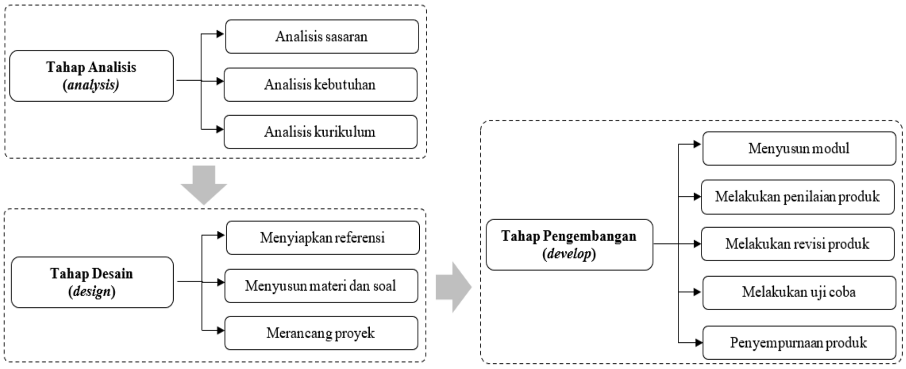


Figure 1. ADDIE model stages

The product assessment design in this development research uses a descriptive design. In the development stage, the initial product is reviewed by expert judgment and revised based on their feedback. Expert judgment in this study involved six chemistry teachers with more than 5 years of teaching experience. After the revisions from the expert judgment, a small-scale trial was conducted with 11 students to gather user responses. The research instruments used for assessing product quality were Likert scale questionnaires. The product quality assessment instrument for expert judgment was adopted from Damayanti & Ikhsan (2024) and includes four criteria presented in Table 1, while the instrument used for the student trial is shown in Table 2.

Table 1. Assessment components for expert judgment

No.	Component	Number of Criteria	Item Numbers
1.	Feasibility/Content	7	1 – 7
2.	Presentation Feasibility	10	8 – 17
3.	Language and Visual Feasibility	11	18 – 28
4.	Graphical Feasibility	5	29 – 33

Table 2. Assessment components for students

No.	Component	Number of Criteria	Item Numbers
1.	Learning/Content	5	1 – 5
2.	Display/Media Operation	7	6 – 12

The final average score conversion to determine the qualitative product quality follows the ideal guideline (Widoyoko, 2009), as presented in Table 3.

Table 3. Ideal assessment criteria

No.	Score Range (i)	Quality Category
1.	$Xi + 1{,}8\ Sbi < \bar{X}$	Very Good
2.	$Xi + 0{,}6\ Sbi < \bar{X} \leq Xi + 1{,}8\ Sbi$	Good
3.	$Xi - 0{,}6\ Sbi < \bar{X} \leq Xi + 0{,}6\ Sbi$	Satisfactory
4.	$Xi - 1{,}8\ Sbi < \bar{X} \leq Xi - 0{,}6\ Sbi$	Poor

No.	Score Range (i)	Quality Category
5.	$X \leq Xi - 1{,}8\ Sbi$	Very Poor

Meanwhile, the ideal percentage calculation can be done using the following formula:

$$\%\ Ideal = \frac{\Sigma \text{score of all expert judgment items}}{\Sigma \text{highest ideal score of all assessment items}} x100\%$$

RESULTS AND DISCUSSION

The project-based green chemistry module was developed by adapting the ADDIE model. However, due to time limitations, only three stages were completed in this study: analysis, design, and development.

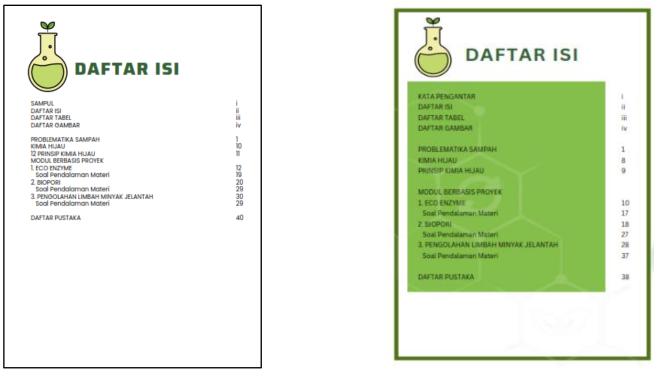
Development Results

Analysis Stage: The development of the module began with analyzing the need for development and the feasibility requirements. The analysis stage includes: a) target analysis, which involved studying the characteristics and cognitive development of students aligned with the design of the module development. Based on interviews with several teachers and students from high schools in Palangka Raya, it was found that students preferred collaborative learning over conventional teacher-centered learning. Some teachers also emphasized that students were more actively engaged in collaborative learning; b) needs analysis, which involved analyzing the availability of teaching materials to support learning. During this stage, interviews were conducted with teachers to determine the availability of teaching materials in schools. It was decided that the teaching material to be developed was a project-based green chemistry module; c) curriculum analysis, which involved analyzing the learning outcomes (CP) in the Merdeka Curriculum. The CP outlined in the green chemistry module aimed to have students observe, investigate, and explain phenomena according to scientific work principles, apply chemistry concepts in environmental management, including explaining global warming phenomena, write chemical reactions, and apply basic chemistry laws. Based on these CPs, students were given the opportunity to be actively involved in learning, with the teacher acting as a facilitator. One teaching model that can facilitate this is project-based learning (PjBL), where students are trained to complete projects independently or in collaboration with teams, integrating their knowledge to solve real-world problems (Sabaryati et al., 2022). In other words, the PjBL model also enhances critical thinking skills (Trimawati et al., 2020; Zahroh, 2020). Therefore, based on the analysis results, the green chemistry module developed is project-based.

Design Stage. The design stage involves the creation of the project-based teaching module for green chemistry. The design stage includes: a) preparing references or literature to create module content; b) compiling materials and questions to be included in the module; c) designing projects for students. Colvin & Chopeta (2011) stated that the visual appeal of a teaching module depends on the visual features, content, learning goals, and student characteristics. In line with this statement, the material was designed based on the results of the analysis stage to ensure the CPs were met. This project-based green chemistry module emphasizes waste management, specifically household waste, as data from Bappenas (2021) shows that most waste comes from households. Additionally, this material encourages students to care about their environment by applying projects included in the module. The projects are easy to implement, as they relate closely to daily life. Some projects that can be implemented for managing household waste in this module include ecoenzymes, biopore systems, and used cooking oil processing.

Development Stage: The development stage aims to create the project-based green chemistry module. This stage includes: a) compiling the project-based green chemistry module; b) assessing product feasibility through expert judgment; c) revising the product based on expert judgment feedback; d) conducting a small-scale trial with students; and e) refining the product. All the material designed in the design stage was then compiled in the development stage to create a draft. The feasibility assessment, both quantitatively and qualitatively, was conducted by six chemistry teachers acting as expert judgment. Revisions were made based on the suggestions and feedback from the expert judgment to improve the product.

Product revisions were made in several sections. Figure 2 shows the revision of the table of contents presentation, which was initially disorganized and lacked structure, but was made more orderly and organized after revision.



(Before revision) (After revision)

Figure 2. Results of table of contents revision

Figure 3 combines two columns into one column to increase display efficiency, in accordance with expert suggestions to improve layout proportions. The figure places the title in the center to attract attention, as per expert input on language appeal criteria.

(Before revision) (After revision)

Figure 3. Results of combining two columns into one

Figure 4 places the article title in the center to capture the reader's attention, as per suggestions to improve title presentation appeal.

(Before revision) (After revision)

Figure 4. Results of placing the article title in the center

Figure 5 changes the font style to a more elegant one to improve visual skills. This aligns with the suggestion to enhance font presentation quality.

(Before revision) (After revision)

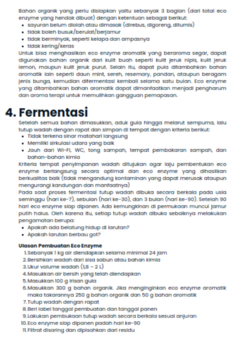
Figure 5. Results of changing the font used

Figure 6 adds captions to the images of key concepts to clarify the material explanations, as per the suggestion to improve image explanation quality.

(Before revision) (After revision)

Figure 6. Results of adding captions to key concepts

Figure 7 adds images of concepts to facilitate students' understanding, as per the suggestion to improve the visual relevance of the material.



(Before revision) (After revision)

Figure 7. Results of adding necessary images to several concepts

Figure 7 revises the numbering of the questions to make them more organized, according to the input for more structured question formatting.

(Before revision) (After revision)

Figure 8. Results of redesigning the layout of question numbers in the material deepening section

Figure 9 adds project examples to provide real-life illustrations of concept applications, as per the suggestion to improve the connection between the material and projects.

(Before revision) (After revision)

Figure 9. Results of adding project example images

The revisions to the images in this module were made based on feedback and suggestions from expert judgment regarding aspects that needed improvement. Several aspects that were revised include the table of contents formatting, layout proportions, title presentation, font quality, image explanations, visual relevance of the material, question structure, and material-project connection. The goal of these revisions was to improve the presentation quality and ease of understanding of the material in the module. A more organized and informative image presentation is expected to attract students' attention and clarify the concept explanations. The layout changes, addition of visual elements, and inclusion of application examples are expected to improve students' learning absorption. Overall, the revisions align with expert suggestions to improve the assessment aspects. The product revisions aim to make the module of higher quality and easier for students to understand (Syahmani et al., 2023). Thus, these revisions are expected to improve the feasibility and quality of the green chemistry learning module.

Product Quality Assessment Results

There are four components assessed in the product quality evaluation by expert judgment: content/material feasibility, presentation, language and images, and graphical design. The content/material feasibility component is assessed based on 7 criteria, presentation based on 17 criteria, language and images based on 11 criteria, and graphical design based on 5 criteria. Each criterion is evaluated by the experts on a scale of 1-5, and the average score is calculated to obtain the final score.

Content/Material Feasibility Component: The presented material was assessed as sufficiently adequate in enriching students' knowledge about green chemistry, especially waste management, with an average score of 4.83. The material was also assessed as very appropriate with correct scientific concepts related to green chemistry, earning a perfect average score of 5.00. For relevance to current conditions and factual accuracy, the material was assessed as highly relevant to each achievement indicator, with a score of 5.00. This indicates that the material is based on actual facts and the latest developments in green chemistry. Thus, the assessment of the content/material quality component overall shows that the material enhances students' understanding in a scientific, up-to-date, and factual manner. The average score obtained for the green chemistry module in the content/material component is 34.33, which falls within the score range $29.41 < \bar{X}$, placing it in the Very Good (SB) quality category with an ideal percentage of 98.08%.

Presentation Component: The assessment criteria for presentation feasibility were evaluated by the experts regarding the systematics and ease of understanding of the material. The material was rated highly logical, receiving a score of 5. The presentation was rated fairly systematic, with an average score of 4.83. The illustrations and messages included were also assessed as creating a pleasant learning atmosphere, with a score of 4.83. The material was considered fairly capable of encouraging positive actions from the reader with a score of 4.67 and was able to stimulate interest and curiosity, with average scores of 4.5 and 4.33. Regarding thought guidance, the material was evaluated as effectively encouraging critical, creative, and innovative thinking, even though the average scores were 4.83 and 4.67. Overall, the presentation was assessed as fairly systematic, although some aspects still need improvement. The average score for the green chemistry module in the presentation component was 34.33, which falls within the score range $42.00 < \bar{X}$, placing it in the Very Good (SB) quality category with an ideal percentage of 94.34%.

Language and Image Component. The language and image feasibility component was assessed by experts regarding the appropriateness of the use of visual and verbal elements in the module. The proportionality of language and images was rated quite well with a score of 4.83. The use of language was considered capable of preventing ambiguous interpretations, earning a score of 4.50. Meanwhile, the clarity of images, the appeal of both language and images, and the correct use of spelling according to PUEBI (Indonesian Spelling System) were assessed as highly adequate with an average score of 5.00. Image captions were rated as still needing improvement, with an average score of 4.50. The use of terms and sentences was considered quite accurate, with scores of 4.83 and 5.00, respectively. The font size, as well as the suitability of the color and shape of images, was rated as needing improvement, with scores ranging from 4.50 to 4.67. Overall, the language and images were assessed as proportional and appropriate, but some aspects still need refinement to enhance reader understanding. The average score for the green chemistry module in the language and image component is 47.17, which falls within the score range $46.20 < \bar{X}$, placing it in the Very Good (SB) quality category with an ideal percentage of 95.45%. The use of proper language in the development of the teaching module indicates that the module adheres to standards. According to Kemdikbud (2017), a teaching module developed with language that follows PUEBI helps students understand the material more easily because clear and well-organized writing reduces ambiguity.

Graphic Design Component. The criteria in the graphic design component assess the design, color selection of images, illustrations, and text in the module. The cover design was rated as excellent with an average score of 4.83. The module's appearance in terms of color, images, illustrations, and font selection was also rated as excellent with an average score of 5.00. The use of paper type and size received an average score of 5.00, indicating a very good assessment by expert judgment. The average score for the graphic design component is 24.33, which falls within the score range $20.99 < \bar{X}$, placing it in the Very Good (SB) quality category with an ideal percentage of 97.32%. Graphic design is an essential component in the preparation of a teaching module and should not be overlooked. Nasir et al., (2023) state that graphic design serves as the visual identity of a product through the use of design elements such as color and images. Graphic design components can also serve as branding to create a consistent and memorable visual representation of a teaching module.

Small-Scale Trial Results. A book is considered good if it is easy for the reader to understand, so the readability level must be considered. The focus of readability testing should include how easy the text is to read according to the reader's age or education level (Latifah et al., 2020). Therefore, the subjects of this small-scale trial were 11 high school students. The small-scale trial assessment consisted of 12 statements. The data analysis for the small-scale trial was conducted similarly to the product feasibility assessment by expert judgment. The average score for the green chemistry module in the learning/material component was 21.64, which falls within the score range $20.99 < \bar{X}$, placing it in the Very Good (SB) quality category with an ideal percentage of 86.56%. Meanwhile, the display/operational media component received a score of 27.91, which falls within the score range $23.80 < \bar{X} \leq 29.41$, placing it in the Good (B) quality category with an ideal percentage of 79.74%. Overall, the small-scale trial results indicate that the product falls into the Good (B) quality category with an average score of 4.13 and an ideal percentage of 82.58%.

CONCLUSION

Based on the data analysis results, it can be concluded that the green chemistry module based on project-based learning is deemed feasible to be implemented in teaching. This is evidenced by the ideal percentage result from the product feasibility assessment by expert judgment, which is 95.95%, placing it in the Very Good (SB) category. Meanwhile, the small-scale trial results show an ideal percentage of 82.58%, placing it in the Good (B) category. This green chemistry module supports the implementation of the SDGs (Sustainable Development Goals) in reducing environmental pollution, as it includes several projects that can be applied by students in the field of waste management.

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