Journal of Educational Analytics (JEDA)
Vol. 4, No. 2, 2025 : 355 – 366

Development of green chemistry teaching modules based on project based learning in class X

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A R T I C L E I N F O

Keywords: Green Chemistry, Teaching Module, Model Project Based Learning

Received : 01, April
Revised : 14, April
Accepted: 15, May

A B S T R A C T

This study aims to develop a valid, practical, and effective Project Based Learning (PjBL) based green chemistry teaching module using the 4-D development model (Define, Design, Develop, Disseminate). The trial subjects were 36 students of class X1 of SMAN 1 Wonomulyo. The instruments used included validation sheets, teacher and student response questionnaires, and learning outcome tests. The results showed that the module was in the category of very valid (average 3.71), very practical (teacher response 94 and students 89.75), and effective (learning completion 94.44%). Thus, the PjBL-based green chemistry teaching module is feasible to be used in learning.

DOI prefik: https://doi.org/10.55927/jeda.v4i2.92
ISSN-E: 2830 – 0432
https://nblformosapublisher.org/index.php/jeda

INTRODUCTION

The 21st century is marked by the rapid development of science and technology that demands the world of education to produce a generation that not only masters basic literacy, but also new literacies, such as technological literacy and human literacy. Education has a strategic role in preparing students to face global challenges through mastering 21st-century skills, including critical, creative, collaborative, and communicative thinking (Redhana, 2019). For this, an innovative and adaptive learning approach is needed, as well as a flexible curriculum, such as the Merdeka Curriculum, which provides space for students to learn according to their interests, talents, and needs (Manalu, Sitohang, & Tunip, 2022).

Chemistry as part of Natural Sciences (IPA) is a conceptual and abstract subject that requires deep understanding. Unfortunately, many students still have difficulty in understanding chemical concepts because learning is less contextual and dominated by teachers (Azisah et al., 2019; Lestari et al., 2021). In SMA Negeri 1 Wonomulyo, even though it has implemented the Merdeka Curriculum as a Driving School, the green chemistry teaching module used has not been fully able to increase student activity and independence.

One approach that is considered effective in increasing the activeness and understanding of chemical concepts contextually is the Project Based Learning (PjBL) learning model. This model provides space for students to build knowledge through real projects that are relevant to everyday life, including the application of green chemistry principles (Ratnawati et al., 2023). Therefore, this study aims to develop a valid, practical, and effective PjBL-based green chemistry teaching module to be applied in phase E chemistry learning in grade X.

LITERATURE REVIEW

21st Century Education and Independent Curriculum

Redhana (2019) stated that education in the 21st century must be able to produce students who have critical, creative, collaborative thinking skills, and good communication skills. Education no longer only focuses on cognitive aspects, but must also pay attention to affective and psychomotor aspects. The Independent Curriculum, as a response to the needs of the times, gives teachers the freedom to adjust learning materials and methods to suit the needs of students. This curriculum emphasizes the importance of contextual learning, the formation of Pancasila student character, and the development of the unique potential of each student (Novianto, 2024; Wahyuddin et al., 2024).

The Role of Teaching Modules in the Independent Curriculum

Teaching modules are teaching tools designed to support teachers in developing systematic and directed learning. Based on Permendikbudristek No. 56 of 2022, teaching modules must meet the criteria of being essential, interesting, meaningful, relevant, and sustainable. Teaching modules not only function as technical guidelines for learning, but also as a medium to create an active and collaborative learning atmosphere. The Ministry of Education and Culture (2020) emphasizes that teaching modules should be designed by

considering the learning needs of students, the local context, and a structured learning objective flow.

Characteristics of Chemistry Learning

Chemistry is a science that contains many abstract concepts such as atomic structure, chemical bonds, and chemical reactions. Misunderstanding one concept can lead to a chain of misconceptions that result in a lack of understanding of subsequent concepts (Azisah et al., 2019). Lestari et al. (2021) emphasized that to improve conceptual understanding, students need to be involved in experimental activities and direct applications, not just listening to or memorizing theories. In addition, Jannah (2020) stated that chemistry learning that is associated with everyday life phenomena can increase student interest and participation.

Green Chemistry in Learning

Green chemistry is an approach in chemistry that emphasizes the importance of reducing negative impacts on the environment through efficient processes and the use of environmentally friendly materials. Mahreni (2019) explains that green chemistry has 12 main principles, including waste prevention, catalyst use, and energy conservation. Ratnawati et al. (2023) added that green chemistry learning can increase students' awareness of the importance of protecting the environment and practicing chemical principles responsibly. The integration of green chemistry concepts in learning is believed to be able to foster students' scientific character and environmental ethics.

Project Based Learning (PjBL) as a Learning Model

The PjBL model is designed to engage students in in-depth investigations of a real-world topic or problem. Budi (2023) stated that this model encourages students to be more independent, think critically, and take responsibility for their own learning. Ratnawati et al. (2023) found that the application of PjBL to green chemistry material significantly increased student activity and learning outcomes. Nuraini (2023) added that PjBL allows students to build knowledge through exploration, experimentation, and presentation of project results collaboratively. According to Trimawati (2020), the advantages of PjBL include building student curiosity, increasing learning motivation, and facilitating cross-disciplinary learning. Zhao & Whang (2022) emphasized that PjBL can also build scientific literacy and prepare students to become responsible citizens.

Integration of Green Chemistry and PjBL in Teaching Modules

The integration of green chemistry with the PjBL model in the teaching module provides a learning experience that is not only based on knowledge, but also on the development of 21st century values and skills. Project-based teaching modules allow students to link theory with practice, and design real solutions to environmental issues. Thus, learning becomes more contextual, collaborative, and has a direct impact on students' mindsets and behaviors towards their surroundings. With this theoretical basis, the development of a

green chemistry teaching module based on Project Based Learning is relevant to be applied in the context of learning at SMAN 1 Wonomulyo, in order to improve the quality of learning, student participation, and form scientific and environmentally conscious characters.

METHODOLOGY

This research is included in the type of research and development (Research and Development). The development model used is the Four-D Model (4-D) which consists of four stages, namely: 1) defining, 2) designing, 3) developing, and 4) disseminating. The product resulting from this research and development is a valid, practical and effective Project Based Learning (PjBL) based green chemistry teaching module. The collected data is presented in the validation results and presentations against categories with a predetermined assessment scale. To determine the quality of the developed teaching module product is valid or not, the study uses validation criteria.

Table 1.Validation Category Five Categories of Teaching Module Development

Range	Category
3.5 ≤X/Y/Z≤4	Very valid
3.0 ≤X/Y/Z<3.5	Valid
2.5 ≤X/Y/Z<3.0	Quite valid
1.5 ≤X/Y/Z<2.5	Less valid
1≤X/Y/Z<1.5	Invalid

Source: Nursyahraini, 2020

The green chemistry teaching module product based on Project Based Learning (PjBL) that has been developed, validated by expert lecturers and media experts and then tested in class X1 Beriman SMA Negeri 1 Wonomulyo in the Odd Semester of the 2024/2025 Academic Year, totaling 36 students. The research instruments used were validation sheets of learning devices and instruments (teaching modules, LKPD, learning outcome tests, implementation observation sheets, teacher response questionnaires, and student response questionnaires). The data analyzed were data on the validity, practicality, and effectiveness of the green chemistry teaching module based on Project Based Learning (PjBL).

RESEARCH RESULT

The Process of Developing Green Chemistry Teaching Modules Based on Project Based Learning (PjBL)

Stage I: Definition (Define)

This stage describes the results of the study in the form of an analysis of the objectives of the limitations of chemical reaction materials and their roles in everyday life which are developed to determine and define learning requirements. This stage includes five steps, namely: initial-final analysis, student analysis, concept analysis, task analysis, and formulation of learning objectives.

Stage II: Design

The design stage includes: 1) selecting the format of the teaching module using the Canva Design application. The preparation of the module uses the help of Microsoft Word 2016, the type of writing used is Time New Roman using font 12; 2) preparation of the teaching module; 3) initial design of the teaching module using an attractive appearance and easy-to-understand language; 4) making the cover and design of the teaching module and 5) making the contents of the teaching module. The design produced at this stage is called Draft 1 and is then developed through the expert validation stage and tested.

Phase III: Development

This stage aims to produce a revised teaching module based on input from experts, as well as data obtained from trial results.

1) Expert validation
   The results of expert validation are one of the main criteria for determining whether the developed teaching module can be used or not. Expert assessments are in the form of small notes on the necessary parts.
2) Trial of teaching modules
   The initial design of the teaching module was validated by experts, then the validation results were used as considerations to revise the teaching module and produce Draft 2, and then tested in class X1 Beriman SMA Negeri 1 Wonomulyo. The data obtained from the trial were then analyzed and the results were used as considerations to revise Draft 2 into the final teaching module which would then be socialized in the distribution process. To test the practicality of the teaching module, observations were made on the implementation of the teaching module, the provision of teacher response questionnaires and student response questionnaires to the teaching module. The results obtained showed that the teaching module was practical because the implementation of the teaching module was in the fully implemented category and the teacher and student response questionnaires were in the very practical category.

To test the effectiveness of the developed teaching module, a test was given to students to measure their mastery of green chemistry material. The results obtained showed that the teaching module was said to be effective because it had met the effectiveness criteria, with an average value of student learning outcomes of 85.94 with class completion of 94.44%.

Stage IV: Dissemination

This dissemination stage was carried out on a limited basis and socialized to chemistry teachers of SMA Negeri 1 Wonomulyo and will be disseminated widely through socialization to chemistry teachers in the Chemistry Subject Teachers' Deliberation (MGMP) community and publication in the UNM Postgraduate Chemistry Education journal, namely Chemistry Education Research (CER).

Quality of Development Results

Validity

Expert validation was conducted to see the validity of the developed teaching module. One of the main criteria for determining whether a teaching module can be used or not is the results of expert validation. Expert assessments are in the form of small notes on parts that need to be improved. In general, the results of the assessment from the two validators showed that all components of the teaching module (Draft 1) were declared valid with minor revisions. Therefore, revisions were made based on expert suggestions and Draft 2 was obtained which was then tested. The results of expert validation of the teaching module can be seen in Table 1.

Table 1.Expert Validation Results Description

No	Assessment Aspects	Evaluation	Category
1.	Module format	3.75	Very Valid
2.	The material (content) presented	3.6	Very Valid
3.	Language	4	Very Valid
4.	Time Allocation	3.5	Very Valid
	Average 3.71 Very Valid		

Similar research was also conducted by Anggi and Leni and has also proven that the use of module-based obtained an average validity score of 3, with a very valid category so that the module is suitable for use.

Practicality

Practicality data of green chemistry teaching module based on Project Based Learning (PjBL) was obtained through observation sheet of teaching module implementation, teacher response questionnaire sheet, and student response questionnaire sheet. Data of observation result of teaching module implementation was obtained from observation sheet filled by observer to assess the implementation of teaching module in learning process, and data of teacher and student response questionnaire result was obtained from questionnaire filled by teacher and students after using teaching module.

In general, the results of expert assessments of the green chemistry teaching module based on Project Based Learning (PjBL) stated that the teaching module is suitable for use in learning. This means that the green chemistry teaching module is compiled in accordance with the principles of development and all module components in the preparation of the teaching module have been listed so that this teaching module can be applied in learning activities. While empirically, based on the results of observations in the trial of the implementation of the teaching module by two observers and the responses of teachers and students to the teaching module can be seen in Table 2.

Table 2.Description of Practical Data Analysis Results

Practicality Instrument	Assessment Aspect	Score Average		Category
Observation of Module Implementation	1. Opening with a question	2		Fully Implemented
	2. Planning the project	1.87		
	3. Supervising the course of the project	1.87	1.83	
	4. Assessment of the resulting product	1.6		
	5. Evaluating the project and translating data and evidence	1.8		Fully Implemented
Teacher Response	1. Teacher 1 (P1)	100		Very Practical
	2. Teacher 2 (P2)	88.46	94	Practical
Student Response	Student Response to Worksheet (LKPD)	89.75	89.75	Very Practical

Based on the results of observations by two observers on the implementation of the teaching module, the average implementation value was 1.83 with the category of being implemented entirely because it was in the range of $1.5 \leq M \leq 2.0$ so that the implementation of the teaching module met the criteria of practicality. This shows that the developed teaching module can be used in chemistry learning, especially in green chemistry material.

ResultsTeachers' responses to the teaching module were identified by giving a questionnaire to teachers to find out their opinions about the developed teaching module. This questionnaire contains statements about the teaching module so that through this questionnaire the practicality of the teaching module can be identified. Based on the results of the analysis of teacher response data, an average score of 94% was obtained, and overall it was in the very practical category because it was in the range of 81%-100%.

The students' responses to the teaching module were known by giving a questionnaire containing statements about the teaching module to students to find out their opinions about the teaching module being developed. Based on the results of the analysis of student response data, a percentage of 89.75% was obtained and overall it was in the very practical category because it was in the range of 81% -100%. This shows that on average students agree with the implementation of learning using the Project Based Learning (PjBL) based teaching module and all aspects asked in the implementation of learning activities using the teaching module received a positive response. From this percentage, it shows that the teaching module is in the very practical criteria. Research on the practicality test of the module based on the results of observations of the implementation of the module was also carried out by Nurhayati, (2023) it was obtained that the practical module with an average

practicality score of 81.34% and was in the fully implemented category. Research on the practicality test of the module based on teacher responses according to Nurhamida, (2023) obtained an average score of teacher responses to teaching devices of 92% and is in the very practical category, which means that the module is easy to use. And for the student response questionnaire, a similar study was also conducted by Yahya, (2020) which showed the results of the analysis of student responses to the module were greater than 70% with good criteria, which means that the LKPD in the developed module is easy to use.

Effectiveness

Effectiveness is obtained through the provision of student learning outcome tests. The test used is a multiple-choice test of 20 numbers which aims to determine the level of student understanding of green chemistry material after learning using the developed teaching module. The final benchmark for the effectiveness of the developed teaching module is that at least 80% of students achieve the learning objective achievement criteria (KKTP) through the learning outcome test, namely 70.

The results of the descriptive analysis of the students' learning outcome test scores after participating in the learning process using the teaching module can be seen in Table 3.

Table 3.Description of Effectiveness Data Analysis Results

Variable	Descriptive Value
Research Subjects	36
Ideal Score	100
Maximum Score	100
Minimum Score	65
Average Score	85.94
Mastery Learning Criteria (MLC)	70
Number of Students Mastered	34
Number of Students Not Mastered	2
Class Mastery Percentage	94.44%

Based on Table 3, it is known that the learning outcomes of class X1 Beriman students of SMA Negeri 1 Wonomulyo using Project Based Learning (PjBL) based teaching modules obtained an average score of 85.94 out of a maximum score of 100 with the lowest score of 65 and the highest score of 100. Of the 36 students who took the learning outcome test, there were 34 students who completed it with a percentage of 94.44% and 2 students who did not complete it with a percentage of 5.56%. Based on the percentage of class completion of students after being taught using the teaching module of 94.44%, it is greater than the minimum class completion percentage of 80% and according to the criteria it has met the classical achievement standards so that it can be concluded that this Project Based Learning (PjBL) based teaching module

has met the criteria for effectiveness and the teaching module is effective for use in the chemistry learning process.

DISCUSSION

The development of Green Chemistry teaching modules based on Project Based Learning (PjBL) through the 4-D model has shown success in producing valid, practical, and effective teaching tools. At the definition stage, an initial analysis was carried out to identify the needs and conditions of students, especially related to chemical reaction material in the context of everyday life. This stage is crucial for designing relevant and contextual learning objectives, in line with the principles of 21st century learning that emphasize connectivity between theory and practice.

At the design stage, the module was designed using digital platforms (Canva and Microsoft Word) to produce an attractive and easy-to-understand display. The module design takes into account aesthetic and pedagogical aspects to increase student interest and understanding. The initial draft of the module (Draft 1) was then validated by experts. The validation results showed that the module had met the validity criteria with an average score of 3.71, included in the very valid category. This indicates that the content, language, format, and time allocation of the module are in accordance with standards and are suitable for use. These results are in line with the findings of Anggi and Leni who also obtained a very valid category in the development of similar modules, confirming that this approach consistently produces quality teaching tools.

At the development stage, the implementation of the teaching module was assessed as very good (1.83), indicating that the learning activities were carried out completely according to plan. The responses of teachers (94%) and students (89.75%) also showed high enthusiasm and acceptance of the use of the module. This positive response strengthens the evidence of the practicality of the module, in line with the findings of Nurhayati (2023) and Nurhamida (2023) who stated that the module developed with the PjBL approach was easy to use and applicable in learning.

Furthermore, in terms of effectiveness, the test result data shows that 94.44% of students achieved learning completion with an average score of 85.94. This percentage is far above the minimum threshold of classical achievement (80%), so it can be concluded that this teaching module is effective in improving students' understanding of green chemistry material. These results support the findings of Yahya (2020) which states that the use of project-based modules can significantly improve students' learning outcomes.

Thus, all aspects of development – from definition, design, development to dissemination – have shown that this PjBL-based Green Chemistry teaching module is feasible, practical, and effective to use in the learning process. This module not only helps teachers in designing student-centered learning, but also increases active participation, learning independence, and students' understanding of applicable and contextual chemistry concepts.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the research and development that has been carried out, it can be concluded that the green chemistry teaching module based on Project Based Learning (PjBL) uses a 4-D development model consisting of four stages, namely the definition stage, the design stage, the development stage, and the dissemination stage. In general, the results of the development of this teaching module meet the criteria of validity, practicality, and effectiveness. The validity criteria based on the results of the validation analysis of the teaching module by the validator are in the very valid category. The practicality criteria based on the results of the analysis of the implementation sheet of the teaching module are in the fully implemented category, and received a positive response from the responses of teachers and students with a very practical category. The effectiveness criteria based on the results of the analysis of student learning outcome tests with a class completion percentage of ≥ 80% is 94.44% so it can be concluded that the teaching module is effective to use.

Based on the research results, it is suggested that the Green Chemistry teaching module based on Project Based Learning (PjBL) can be utilized by teachers as an alternative teaching material in the implementation of the Independent Curriculum, especially to improve student activity, independence, and learning outcomes. Schools are expected to encourage teachers to develop and use similar modules that are relevant to the learning context. In addition, the Chemistry MGMP can use this module as a reference in a collaborative forum for the development of innovative and applicable teaching tools. Further researchers are advised to develop similar teaching modules on different topics or combine them with other learning approaches to examine their effects on students' critical, creative, and scientific literacy thinking skills.

ADVANCED RESEARCH

Further research that can be conducted based on the results of this study is to develop a Green Chemistry teaching module based on Project Based Learning (PjBL) by integrating aspects of scientific literacy and critical thinking skills of students. This study can use a similar development model (4-D) but with a focus on measuring the improvement of scientific literacy and critical thinking skills through pretests and posttests, as well as observing student activities during learning. In addition, further research can also expand the trial subjects to schools with different characteristics to test the implementation and acceptance of the module more widely. Aspects of long-term impacts on environmental awareness and sustainable behavior of students can also be the focus of further research.

ACKNOWLEDGMENT

The author would like to express his gratitude to all parties who have helped in the implementation and completion of this research. In particular, the author would like to thank the teachers and students of class X1 Beriman SMAN 1 Wonomulyo for their participation and cooperation during the trial of the teaching module. The author also expresses his highest appreciation to the

validators who have provided valuable input in the development of the module, as well as to all colleagues and supervisors who have provided support, motivation, and direction during the research process. Hopefully this research can contribute to the development of more innovative and meaningful chemistry learning.

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