Sosioedukasi
JURNAL ILMIAH ILMU PENDIDIKAN DAN SOSIAL
ISSN: 2086-6135 E-ISSN: 2541-612x
Volume 15 No. 2. June 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

DEVELOPMENT OF GREEN CHEMISTRY LEARNING MODULE INTEGRATED WITH CO-CURRICULAR PROJECTS TO IMPROVE THE QUALITY OF HIGH SCHOOL GRADUATES

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ARTICLE HISTORY
Received : 20-05-2026
Revised : 13-06-2026
Accepted : 30-06-2026

KEYWORDS
Learning Modules, Green Chemistry, Co-Curricular Projects, Graduate Quality, 21st Century Education

ABSTRACT
This study aimed to develop an integrated green chemistry learning module for co-curricular projects to enhance the quality of senior high school graduates by improving knowledge mastery, scientific process and practical skills, Higher-Order Thinking Skills (HOTS), attitudes and character, as well as 21st-century competencies, including scientific literacy, numeracy, and digital literacy. The study was motivated by the predominance of chemistry teaching materials that primarily emphasize theoretical concepts while providing limited integration of environmental issues and project-based learning activities that foster holistic graduate competencies. The novelty of this study lies in the development of a green chemistry module that systematically integrates green chemistry principles with co-curricular project-based learning within the ADDIE instructional design framework, enabling students to simultaneously develop cognitive, practical, environmental, and 21st-century competencies. Unlike existing green chemistry teaching materials, the proposed module emphasizes authentic project implementation and graduate quality outcomes through a comprehensive competency-oriented approach. This research employed the Research and Development (R&D) method using the ADDIE Branch model, consisting of the analysis, design, development, implementation, and evaluation stages. The research participants included material experts, media experts, chemistry teachers, and Grade X Phase E students of SMA Negeri 2 Jambi City. Data were collected through interviews, questionnaires, expert validation, student response questionnaires, and graduate quality assessments, and were analyzed using descriptive qualitative and quantitative techniques. The findings indicate that the developed module possesses contextual, innovative, and project-based characteristics and was rated as highly feasible by experts, teachers, and students. Furthermore, the effectiveness test revealed a significant improvement between the pre-test and post-test scores, with an N-Gain value of 0.7130 (moderate category), demonstrating that the module is effective in improving the quality of student graduates

INTRODUCTION

According to Edward Sallis (2008), the quality of education is not solely positioned as the final goal

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of the implementation of education, but as an important instrument to assess the extent to which an educational institution has reached the standards that have been set previously. In the context of quality management, education can be analogized as a product or service whose results must be able to meet the needs, expectations, and provide satisfaction to users of educational services. Thus, the quality of education is seen as an integrative and dynamic concept, which includes all aspects of education implementation from inputs, processes, to outputs. Efforts to improve the quality of education must always be directed at meeting the needs of service users and end users, so that educational institutions can maintain their relevance and credibility in the face of changing global changes and demands.

In the midst of the ongoing era of digitalization, students are faced with the task of sorting out reliable information and utilizing it effectively in their daily lives. Therefore, in the 21st century, education should focus on developing scientific talents in students, so that they can become resourceful, intelligent, and flexible individuals who are able to adapt to change (Halim, 2022). The development of students' abilities is essential not only to achieve academic achievement, but also to equip students to face global issues, both in the professional world and in an increasingly complex social environment. Engaging in reading activities is one of the aspects of effective education, especially in science learning. Through well-designed reading activities, students not only absorb information, but also engage in the process of constructing scientific content. Reading activities are very important in education, because they help students develop critical and analytical thinking skills, which are basic skills in scientific learning (Hasan et al., 2022).

Based on this, the development of the quality of human resources (HR) plays an important role in efforts to improve 21st century skills, which are increasingly needed in the midst of fierce global competition. Education, as one of the main pillars in building quality human resources, has urgency in preparing students to be ready to contribute to society and the state (Puspa et al., 2023). Through education, students are equipped with critical skills, creativity, communication skills, and collaboration, which are at the core of 21st century skills. In addition, education also forms the character and moral values needed to play a role in society. Educational interventions not only serve to meet individual needs, but also to ensure that the nation has human resources who are able to compete and innovate at the global level, so that they can continue to develop (Farid, 2023).

According to data from the Puspendik Kemdikbud (2018), the quality of the student learning process in Indonesia currently shows a condition of disorientation, which indicates that the learning environment provided by teachers has not met the standards needed to support effective learning. These include a lack of adequate affective or attitudinal support, a lack of cognitive activation that encourages student engagement, and the achievement of literacy skills that are below the required level of competence. This condition is very concerning, considering that in Natural Sciences (IPA) learning, science literacy skills and science process skills are very important (Nuraini, 2021). Science literacy skills enable students to understand and use scientific information effectively, while science process skills include critical thinking, experimentation, and data analysis skills that are essential for good scientific understanding (Danianty, 2022).

The quality of science education in Indonesia is still very low. This is evident from the PISA test results in the last 12 years, since 2010 Indonesia has been in the bottom 10 out of 70-80 countries in the world (PISA, 2022). Therefore, to make the quality of science education in Indonesia improve, a deep learning is needed for students. According to the Minister of Education Regulation no. 13 of 2025 regarding deep learning, namely deep learning is a glorious approach to improve student competence optimally. The framework of deep learning work consists of four components, namely (1) the dimension of the graduate profile, (2) the learning principles, (3) the learning experience, and (4) the learning framework. Deep learning is focused on achieving the eight dimensions of the graduate profile. The profile of graduates is achieved through the principles of awareness, meaning, and exhilarating. This principle is realized through students' learning experiences, namely understanding, applying and reflecting and supported by pedagogical practices by educators who focus on authentic student learning experiences, a varied, integrated learning environment that provides safety and comfort to students, the use of digital technology as a catalyst and the existence of learning

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partnerships that form collaborative relationships.

The purpose of this co-curricular project is to provide an experiential learning experience that is able to enrich students' understanding of the material taught in class. In the context of green chemistry, co-curricular projects provide opportunities for students to apply the principles of green chemistry in real situations, by utilizing the surrounding environment. Green chemistry is one of the concepts of chemical thinking developed in education to participate in the process of sustainable development. Green chemistry, also known as sustainable chemistry, is used to design chemical products and procedures that reduce the formation of harmful chemicals. The process of designing safe chemical products and procedures will use the principles of green chemistry (Anastas, 2001). According to Haack (2005), the integration and implementation of the 12 principles of green chemistry in the curriculum and learning is referred to as green chemistry education. This is done in the hope of developing students' environmental awareness from an early age. Chemistry education has a central role in education for sustainable development, especially sustainable chemistry (Burmeister, 2012).

Chemistry that prioritizes the concept of green chemistry has great potential to support the achievement of the SDGs by providing an understanding of how chemistry can be optimized to address increasingly complex environmental problems (Paristiowati et al., 2022; Sari, 2023). With the concept of green chemistry, chemical products and processes will be more environmentally friendly, sustainable, and safe for human health, so that they can contribute significantly to the achievement of the set global goals (Santosa et al., 2024). By integrating the principles of green chemistry in the educational curriculum, students will be equipped with the relevant skills and knowledge to learn how chemistry can provide innovative solutions to environmental challenges faced today and in the future (Jusniar et al., 2023).

Based on the initial observation interview conducted by the researcher with one of the teachers of chemistry class X at SMAN 2 Jambi City, information was obtained that SMAN 2 Jambi City has used an independent curriculum for class X. The results of observations show that the chemistry learning process is still dominated by lecture methods and practice questions, with relatively low student involvement in practicum activities and contextual discussions. Learning focuses more on completing materials and preparing for exams, while applicative aspects such as the application of chemical concepts in daily life and environmental issues have not been explored optimally. Project activities or co-curricular activities related to chemistry and the environment are also still limited, so students tend to view chemistry as a difficult and less interesting theoretical subject. Through interviews with chemistry teachers, information was obtained that green chemistry materials have actually been mentioned at a glance in the context of environmental conservation, but there are no specific teaching materials that integrate the concept with project-based learning activities. Teachers said that students often have difficulty understanding the relevance between the chemical concepts they learn and their impact on the environment, due to the lack of concrete examples and practical activities that involve them directly.

The results of interviews with students of class X of MIPA show that most of them are not familiar with the term "Green Chemistry". However, when it is explained simply that green chemistry is related to efforts to reduce waste, use of safe materials, and energy efficiency, students show high enthusiasm and curiosity. They state that learning chemistry would be more interesting if it was associated with a real project, such as school waste treatment, the creation of eco-friendly products, or simple experiments that demonstrate the impact of chemistry on environmental sustainability. These findings indicate a gap between the learning needs of students and the available teaching materials. Students need teaching materials that are contextual, applicative, and interactive, which not only convey the concept of green chemistry theoretically but also provide a meaningful learning experience through project activities. This condition encourages researchers to develop Green Chemistry learning modules that are integrated with co-curricular projects, so that students not only understand the principles of green chemistry but are also able to apply them in real life in their daily lives.

Strengthened by the results of observations that have been carried out by researchers using google forms in several schools in Jambi City regarding the understanding of green chemistry or environmental

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chemistry to students, it shows that only 39.4% of students understand green chemistry materials and the remaining 60.6% of students do not understand green chemistry. Based on the results of the observations obtained, generally students have difficulty in understanding several sub-materials of green chemistry, including the concept of environmental chemistry, the concept of global warning, the principle of green chemistry, greenhouse gases CH_4 and CO_2, food preservatives, the concept of fre on, knowledge of detergent effects, PETI and the glabal warning mechanism. Therefore, a teaching material is needed that can help students learn independently.

To meet the learning demands of students in high school, it is necessary to be equipped with the quality of student graduates, one of the effective learning models to achieve this is through project-based learning or Project Based Learning (PjBL) (Syamsuddin et al. 2022). PjBL is a learning model that places projects as the center of learning activities, so that students can develop various skills (Hartono & Asiyah, 2018). PjBL starts by identifying problems to create concrete solutions in the real world to solve problems (Kong et al. 2024). According to Woods (2013), PjBL emphasizes the development of practical skills such as problem solving, the ability to work with a team, and better long-term knowledge. Research by Lozano et al. (2022) shows that implementing PjBL in ESD learning can improve students' skills. In addition, research by Granado-Alcón et al. (2020) shows that an increase in students' knowledge and skills occurs in learning that implements PjBL in ESD learning.

To optimize the quality of high school graduates, an innovation of learning media is needed to be more effective in the learning process in the form of green chemistry learning modules that are integrated with co-curricular projects in order to help and make it easier for students to learn more deeply about science, scientific methods, or scientific concepts. Therefore, the researcher is interested in conducting a research with the title "Development of Green Chemistry Learning Module Integrated with Co-Curricular Projects to Improve the Quality of High School Graduates".

To address the demands of 21st-century learning and improve graduate quality, instructional innovation should not only facilitate conceptual understanding but also provide authentic learning experiences that promote critical thinking, collaboration, creativity, and problem-solving skills. One pedagogical approach that has consistently demonstrated its effectiveness in achieving these outcomes is Project-Based Learning (PjBL). PjBL positions students as active learners who construct knowledge through the investigation of authentic problems and the development of tangible products, thereby integrating cognitive, affective, and psychomotor competencies (Hartono & Asiyah, 2018; Woods, 2013). Recent studies further indicate that PjBL contributes significantly to improving scientific literacy, environmental awareness, communication skills, and higher-order thinking skills, particularly when implemented within Education for Sustainable Development (ESD) contexts (Lozano et al., 2022; Kong et al., 2024).

In chemistry education, several recent studies have integrated PjBL with environmental and sustainability themes to promote students' understanding of green chemistry concepts. These studies generally report improvements in students' conceptual understanding, environmental attitudes, and scientific process skills (Granado-Alcón et al., 2020; Jusniar et al., 2023; Paristiowati et al., 2022). Nevertheless, the majority of existing studies focus primarily on the implementation of project-based learning or the integration of green chemistry concepts as classroom learning strategies. Only a limited number of studies have developed comprehensive instructional modules that systematically integrate green chemistry principles with co-curricular project activities while simultaneously assessing graduate quality through multidimensional competencies, including knowledge, practical skills, Higher-Order Thinking Skills (HOTS), character, scientific literacy, numeracy, and digital literacy.

This limitation indicates a clear research gap. Existing green chemistry teaching materials have not adequately accommodated the implementation of co-curricular projects as part of the Deep Learning framework promoted in the Indonesian education system. Furthermore, most available modules emphasize conceptual mastery without providing structured project guidelines that enable students to experience authentic problem-solving related to environmental sustainability. Consequently, there remains a need for innovative teaching

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materials capable of connecting classroom learning with real-world environmental issues while fostering comprehensive graduate competencies.

The preliminary study conducted at SMA Negeri 2 Jambi City reinforces this gap. Classroom observations and interviews with chemistry teachers revealed that learning activities remain predominantly teacher-centered and emphasize theoretical content and examination preparation. Although environmental issues have occasionally been introduced, no instructional module has systematically integrated green chemistry principles with project-based co-curricular learning. Interviews with Grade X students further revealed that most students were unfamiliar with green chemistry concepts but expressed strong interest in learning through authentic environmental projects, such as waste management, eco-friendly product development, and simple experimental investigations. A broader survey conducted in several senior high schools in Jambi City also showed that only 39.4% of students understood green chemistry concepts, while 60.6% demonstrated limited understanding of essential topics such as green chemistry principles, greenhouse gases, environmentally friendly chemical processes, and sustainable resource management.

These findings indicate that students require contextual, project-oriented, and competency-based teaching materials that support meaningful learning experiences. Therefore, this study develops a Green Chemistry learning module integrated with co-curricular projects using the Project-Based Learning (PjBL) approach. The novelty of this research lies in the integration of green chemistry principles, co-curricular project activities, and the Deep Learning framework into a single instructional module designed not only to improve students' conceptual understanding but also to enhance graduate quality through the development of scientific literacy, numeracy, digital literacy, Higher-Order Thinking Skills (HOTS), practical skills, and character. Accordingly, this study aims to develop, validate, and evaluate the effectiveness of the integrated module in improving the quality of senior high school graduates.

METHODS

The type of research used is Research and Development (R&D) with the aim of producing an educational product in the form of an integrated green chemistry learning module for high school graduates, a quality co-curricular project, especially for students of class X MIPA SMA specially designed by the developer. The products developed are tested through a series of stages, both from the stages of validation, trial and implementation to meet the criteria, namely valid (according to content and construct), practical (easy for teachers and students to use), and effective (improving students' learning outcomes, creativity, and science literacy).

The development model chosen is the model of Robert Maribe Branch (2009) which adopts the ADDIE (Analyze, Design, Develop, Implement, Evaluate) framework. The development model of this branch consists of five stages of development, namely Analyze, Design, Develop, Implement, and Evaluate. This research and development uses a development procedure that includes 5 steps and stages of research proposed by Robert Maribe Branch, namely the Analyze Stage, the Design Stage, the Development Stage, the Implementation Stage, and the Evaluate Stage.

Furthermore, product trials of the integrated green chemistry learning module of this co-curricular project were carried out to find out whether a product has been categorized appropriately or not. The subjects of the product trial are students: high school students in class X SMAN 2 Jambi City, chemistry teachers: acting as learning facilitators using learning modules, the population in this study is all students of class X/E SCIENCE SMAN 2 Jambi City. The sampling technique uses random sampling where samples are randomly selected from the population. The use of random sampling techniques is based on the school system where schools randomly place students in each school, so that the sample can be representative of the population. The location of this research was carried out at SMAN 2 Jambi City.

The trial is carried out in one stage, namely the Main Field Test. The research uses the design of the Quasi-experiment method with One-Group Pretest-Posttest Design This design uses one test group, namely the experimental class by conducting a pretest and posttest. The scores from the pretest and posttest show the

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effectiveness of the product on the quality of student graduates in green chemistry materials.

Table 1 Trial design table

Class	***Pretest***	**Treatment**	
	Posttest Experiment	O_1	

x O_2

Description:
X: Chemistry learning using co-curricular project integrated learning
modules O_1: Pretest given before treatment
O_2: Posttest given after treatment

In this development research, the type of data used is in the form of qualitative data and quantitative data, in accordance with the characteristics of research and development (Research & Development). R&D research generally uses a mixed method. where researchers combine qualitative data to understand the process, context, and input in depth, as well as quantitative data to measure the effectiveness, validity, and practicality of the resulting product. In this development, data in qualitative form is used to be able to obtain a descriptive picture, be it in the form of opinions, perceptions, inputs, criticisms or suggestions from various parties involved in the research. This data is narrative and analyzed in a qualitative descriptive manner. Meanwhile, data in quantitative form is used to provide a numerical measure of the quality of green chemistry learning modules that are integrated with co-curricular projects. This data can be in the form of scores, percentages, and learning outcome scores that can be processed using descriptive and inferential statistical analysis.

1. Qualitative data: Obtained from the results of interviews in the form of narratives from teachers and students), observation records of student collaboration activities during the project, and supporting documentation, be it photos or videos of activities. This data was analyzed in a thematic descriptive manner to identify key fin dings.
2. Quantitative data: Obtained from test results in the form of pretest and posttest, literacy, creativity and student collaboration questionnaire scores, and teacher assessments in the form of assessment scores for the implementation of green chemistry learning modules integrated with co-curricular projects. This quantitative data is in the form of numbers and is analyzed with descriptive statistics and significant tests

Qualitative data collection instruments are interviews, materials for integrated learning modules for co-curricular projects, media for integrated green chemistry learning modules for co-curricular projects and questionnaires for teachers' responses related to learning tools and their implementation. Quantitative Data Collection Instruments are Using Questionnaires and Essay Questions.

Data analysis was carried out descriptively, quantitatively, and qualitatively using validity tests, normality tests, homogeneity tests, Paired Sample t-Test, and N-Gain tests to determine the effectiveness of the modules.

RESULTS AND DISCUSSION

Stages of Analysis

The needs analysis stage was carried out through interviews with chemistry teachers in class X of SMA Negeri 2 Jambi City and the distribution of instruments to students who had studied green chemistry material. The results of the analysis show that students still have difficulty understanding abstract chemical concepts because learning focuses more on theory. The teaching materials used are also still limited to package books and are not equipped with interesting and contextual modules. As many as 60.6% of students admitted that they had difficulty understanding green chemistry material, so teaching materials were needed that could increase students' motivation and involvement in learning. The findings suggest that green chemistry learning

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requires a more contextual approach so that concepts can be understood more meaningfully (Putri, 2025).

Analysis of student characteristics shows that the majority of students have a high interest in chemistry learning when supported by media that allows them to learn independently. As many as 91.7% of students stated that they prefer the use of learning media that can be learned independently, while 86.1% of students are interested in using integrated learning modules of co-curricular projects. The results of interviews with teachers also show that the teaching materials that have been used have not been able to provide optimal understanding to students. Teachers support the development of project-based modules because they are assessed in accordance with the implementation of the Independent Curriculum and have given good results in other materials. This condition shows that project-based learning can improve the quality and interest of students learning more effectively (Sari, 2023).

The analysis of learning objectives was carried out by referring to the Independent Curriculum phase E which was implemented at SMA Negeri 2 Jambi City. The learning outcomes formulated emphasize the ability of students to understand the concepts and principles of green chemistry, analyze the impact of chemicals on the environment, and design sustainability-based solutions. Learning objectives are developed to a high level of thinking ability, starting from analyzing to creating a simple product or project based on green chemistry. In addition, learning indicators are compiled to support students' critical thinking, problem-solving, and scientific communication skills. The preparation of these learning objectives is in line with the characteristics of the Independent Curriculum which emphasizes contextual learning and 21st century competency development (Kemendikbudristek, 2022).

The analysis of the material shows that the concept of green chemistry is still considered difficult to understand by most students because it is abstract and requires high-level thinking skills. Students have difficulty in connecting the principles of green chemistry with environmental problems in their daily lives. As many as 91.7% of students stated that they needed learning media that could help understand the material more concretely, while 94.4% of students wanted project-based learning activities. This condition shows that learning that is only theoretical has not been able to provide a meaningful learning experience. Therefore, integrated learning modules of project-based co-curricular projects are seen as an alternative that can increase understanding of concepts, creativity, and concern for the environment (Sari, 2023).

Analysis of educational technology shows that SMA Negeri 2 Jambi City already has learning support facilities in the form of internet networks, LCD projectors, laptops, and digital platforms such as Google Classroom. The facility supports the implementation of the Independent Curriculum which is oriented towards student-based learning and strengthening 21st century competencies. However, the use of technology in chemistry learning is still not optimal because the learning process is still dominated by lecture methods and the use of conventional teaching materials. The results of the needs instrument show that students want more interactive, visual, and contextual learning media to help understand green chemistry materials. Thus, the development of green chemistry learning modules integrated with co-curricular projects is a relevant solution to support more effective learning and in accordance with the demands of today's education (Kemendikbudristek, 2022).

Design Stage

The design stage of this research began with the design of an integrated green chemistry learning module for co-curricular projects aimed at improving the quality of high school graduates. Design activities include forming a development team, preparing research schedules, determining media specifications, preparing material structures, and creating flowcharts and storyboards. The development team consists of researchers, supervisors, expert validators, practitioner teachers, and students as product users. The research was carried out in the range of July 2025 to May 2026 with stages that were systematically arranged to obtain quality products. The module design is carried out with reference to the ADDIE Branch model so that each stage of development has a clear direction and goals (Branch, 2009).

The products developed are in the form of printed learning modules that can be used in classroom

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learning activities and school environment projects. The module structure is systematically arranged and includes a cover, instructions for use, concept map, learning objectives, green chemistry materials, project activities, reflections, final evaluation, and a bibliography. The material presented includes the basic concepts of green chemistry, the principles of green chemistry, benefits in daily life, and its application in waste management. The module also contains project-based learning that allows learners to be directly involved in environmental activities collaboratively. The preparation of the material refers to the learning outcomes of phase E of the Independent Curriculum and the Learning Objectives Flow used at SMA Negeri 2 Jambi City (Kemendikbudristek, 2022).

The characteristics of the developed modules show an orientation to 21st century learning and strengthening environmental awareness. The modules are designed based on the principles of green chemistry and integrated with co-curricular projects so that students can connect chemistry concepts with real problems in the surrounding environment. Attractive visual design and the use of illustrations and infographics support the ease of understanding the concept. In addition, the modules are adaptive so they can be used in face-to-face and blended learning. Product development also pays attention to the feasibility aspects of content, presentation, language, and display so that the modules have good quality and are in accordance with the characteristics of students (BSNP, 2014).

The design stage continues with the preparation of flowcharts and storyboards as the basis for product development. Flowcharts are used to systematically describe the learning flow from the identification of environmental problems to the reflection of learning outcomes. Meanwhile, the storyboard is structured by integrating text, images, and learning activities that will later be implemented using the Canva application. The preparation of the two components aims to produce an attractive and easy-to-understand module display by students. The existence of flowcharts and storyboards helps developers maintain consistency in the content and presentation of the material during the development process (Smaldino et al., 2015).

The development of green chemistry learning modules is influenced by constructivism theory, social learning theory, contextual, cognitivism, and behaviorism. Constructivism theory encourages learners to build knowledge through real-world experiences, while social theory emphasizes the importance of collaboration in project-based learning. The contextual approach connects the concept of chemistry with environmental problems so that learning becomes more relevant for students. On the other hand, the theory of cognitivism plays a role in the logical arrangement of material, while behaviorism supports the formation of scientific behavior and concern for the environment. The integration of these various theories makes the module not only increase mastery of concepts, but also develop critical thinking skills, creativity, communication, collaboration, and the character of students that support sustainable development (Arends, 2012).

Development Stage

At the development stage, the researcher produced an integrated green chemistry learning module of a co-curricular project that contains various components, such as concept maps, materials, project LKPD, reflections, and student assessments. The product is compiled using the Canva application with the aim of producing engaging and easy-to-use teaching materials. The feasibility of the product is then tested through validation of material experts and media experts. The results of the validation of material experts obtained an average score of 4.20 with the very feasible category, while the validation of media experts obtained an average score of 4.72 with the very feasible category. All suggestions given by validators have been revised so that the modules are declared to meet the conceptual, procedural, and media aspects for use in learning. These findings show that the products developed have met the characteristics of good teaching materials and are in accordance with the needs of students (Rahayu, 2024).

The assessment of chemistry teachers showed that the developed modules obtained an average score of 4.9 in the excellent category. The teacher assessed that the material presented was in accordance with learning

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outcomes, easy to understand, and had an attractive appearance. In addition, the existence of a simple project based on green chemistry is considered to be able to connect the concept with daily life. Students' responses to one-on-one, small group, and field trials also showed excellent categories with consecutive averages of 4.37; 4,53; and 4.35. Students stated that the modules were easy to use, engaging, and helped them understand green chemistry materials in a more contextual way. These results show that the module has a high level of practicality and is able to increase students' learning motivation through project-based learning experiences (Bell, 2010).

The effectiveness of the module was measured through the implementation of pre-tests and post-tests on 35 students. The average pre-test score of 46.17 increased to 85.14 in the post-test. Before hypothesis testing, the data were first tested using Shapiro-Wilk and showed that the data was normally distributed. The results of the paired sample t-test produced a t-count value of 17.846 which was greater than the t-table of 3.533 with a significance value of less than 0.05. The findings showed a significant difference between learning outcomes before and after the use of the module. Thus, the green chemistry learning module integrated with co-curricular projects has been proven to have a real influence on improving the quality of student graduates (Salman, 2024).

Analysis using the N-Gain test showed a value of 0.7130 or 71.30% which is in the moderate or moderately effective category. The improvement occurred in all graduate quality indicators which included cognitive, psychomotor, HOTS, affective, and 21st century competencies. The highest improvement occurs in the ability of Higher Order Thinking Skills because project-based learning encourages students to analyze, evaluate, and design solutions to environmental problems. Cognitive and psychomotor aspects also experienced a high increase as students gained contextual and practice-based learning experiences. Meanwhile, 21st century competencies received the lowest scores in the post-test because students' digital literacy and numeracy skills still vary. These results show that project-based learning is able to develop students' high-level thinking skills and problem-solving skills effectively (King, 2010).

Overall, the green chemistry learning module integrated with the co-curricular project was declared valid, practical, and effective for use in chemistry learning in high school. The integration of co-curricular projects provides opportunities for students to apply the concept of green chemistry in real-world situations related to environmental issues. Project activities encourage the development of knowledge, skills, character, and competencies in the 21st century in an integrated manner. Learning that is oriented towards solving real problems also results in a more meaningful learning experience and supports continuous education. Therefore, the application of co-curricular projects in green chemistry learning has great potential to improve the quality of student graduates. These findings are in line with the view that project-based learning is effective in developing the competencies needed in the 21st century and supporting Education for Sustainable Development (Mota, 2025).

Evaluation Stage

The evaluation stage in the development of green chemistry learning modules integrated with co-curricular projects includes formative evaluation and summative evaluation. Formative evaluation is carried out through the validation of material experts, validation of media experts, teacher assessments, and student responses at various stages of the trial. The validation results showed that the module received a very worthy category from material experts and media experts. Teachers' assessments showed that the category was very good, while the students' responses to the one-on-one, small-group, and large-group trials were also in the very good category. The findings show that the modules are of high quality and are suitable for use as innovative teaching materials in green chemistry learning (Branch, 2009).

The learning modules developed received positive responses from teachers and students because they were easy to understand, easy to use, and had an attractive appearance. The projects presented utilize simple materials available in the surrounding environment so that they are easy to apply in daily life. Students can also connect the concept of green chemistry with real problems and generate creative ideas through project activities. The existence of LKPD, reflection questions, and sample application materials also increase students' motivation to learn. Thus, project-based learning modules are able to support more contextual and meaningful learning for learners (Madybekova et al., 2025).

Although it has been declared valid, practical, and quite effective, the implementation of the module still faces some limitations. The implementation of co-curricular projects takes longer than conventional learning because students must go through the stages of observation, planning, implementation, and presentation of results. The uneven availability of facilities and infrastructure between schools can also affect the quality of project implementation. In addition, the difference in student participation in group work and digital literacy skills causes the achievement of 21st century competencies to not take place optimally for all students. Therefore, teachers need to carry out time management, mentoring, and assessments that pay attention to the contributions of individuals and groups (Mota et al., 2025).

The measurement of the quality of graduates in this study is still limited to cognitive, psychomotor, HOTS, affective, and 21st century competencies. Other aspects such as communication skills, leadership, entrepreneurship, and adaptability have not been evaluated in depth. To overcome these limitations, the implementation of the project can be adjusted to school conditions through the use of local materials and the use of technology in stages. Cooperation between teachers, schools, and students also needs to be strengthened so that the implementation of the project can take place optimally. The development of sustainability competencies and 21st century skills requires a continuous process and adequate learning environment support (UNESCO, 2024).

Summative evaluation was carried out to determine the effectiveness of the module in improving the quality of student graduates. The results of the Paired Sample t-Test test show that there is a significant difference between the pre-test and post-test scores so that the module is proven to have a meaningful influence on student learning outcomes. The N-Gain analysis yielded a score of 0.7103 which was in the category of moderately effective or moderate. The findings show that the module is able to improve the cognitive, psychomotor, HOTS, affective, and 21st century competencies of students. Therefore, the integrated green chemistry learning module of the co-curricular project has the potential to be an innovative alternative teaching material that supports contextual, meaningful, and sustainable development-oriented chemistry learning (Branch, 2009).

CONCLUSION

The results of the study show that the integrated green chemistry learning module of co-curricular projects has been successfully developed using the ADDIE Branch model through the analyze, design, develop, implement, and evaluate stages so as to produce teaching materials that combine green chemistry materials with Project Based Learning (PjBL)-based project activities. The resulting products consist of various learning components, then validated by material experts, media experts, chemistry teachers, and tested on students through one-on-one, small group, and large group tests. The results of validation and user responses show that the module meets the feasibility aspects of content, presentation, display, and use so that it is declared valid, practical, and feasible for use in high school chemistry learning. The development of modules is also based on constructivist theory, social theory, contextual theory, cognitivism theory, and behaviorism theory that support meaningful and student-centered learning. The implementation of the module in class X Phase E students of SMA Negeri 2 Jambi City showed a significant improvement in the quality of graduates based on the results of the Paired Sample t-Test with a t-count value of 17.846 greater than the t-table of 3.533 and a significance value of less than 0.05. The N-Gain test result of 0.7130 is in the medium category, which shows that the module is quite effective in improving knowledge mastery, process skills, HOTS, affective aspects, and 21st century competencies. The findings prove that the integration of green chemistry-based co-curricular projects is able to provide a contextual learning experience and contribute positively to improving the quality of high school graduates.

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ISSN: 2086-6135 E-ISSN: 2541-612x
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