



**Fostering Students' Creative and Ethical Character through Green Chemistry
Modules in Project-Based Learning in Wetland Ecosystems**

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Article Info	Abstract
Article history: Received: March 10, 2026 Accepted: April 25, 2026 Published: May 25, 2026	Creative and ethical character development is an essential competency in life and career skills in the 21st century. However, schools in wetland ecosystems have not optimized this character development because appropriate learning modules are not yet available. Therefore, this study aims to analyze the effectiveness of a project-based learning (PBL)-oriented green chemistry module in fostering students' creative and ethical character in wetland ecosystems. This study is part of a research and development program using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model focused on the Development, Implementation, and Evaluation (DIE) stages. This study involved 15 students in the limited test and 33 students in the field test. The researchers collected data using a character questionnaire instrument, a project outcome assessment, and documentation. Then they analyzed the data descriptively using the n-gain test and paired-samples t-tests or Wilcoxon tests. The results showed that the distribution of student character categories increased from lower categories to higher categories. In the limited test, students who were originally in the good and very good categories all increased to the very good category. In the field test, students who were initially distributed across the good and very good categories (81.25%) shifted to the very good category (90.63%). Students' creative and moral character increased significantly in both the limited test and the field test with a moderate increase category ($p < 0.05$; $n\text{-gain} = 0.54$), and students' project results were in the very good category. Thus, the implementation of the PBL-oriented green chemistry module has proven effective in fostering students' creative and moral character in wetland ecosystems.
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INTRODUCTION

The 21st-century education not only prepares an intelligent and skilled generation but also cultivates creative and moral character in its surroundings. In line with the Sustainable Development Goals (SDGs), the education sector is expected to protect and preserve the environment and use it creatively and responsibly (Akinsemolu & Onyeaka, 2025;

Velempini, 2025). In this context, the principles of green chemistry need to be integrated into science learning in schools (Sari & Saputro, 2025) so that students not only understand chemical concepts but also realize the impact of chemical activities on environmental sustainability and the importance of using more environmentally friendly materials and processes (Kurul et al., 2025; Vaz et al., 2025).

Environmental education is becoming increasingly important as global ecosystems deteriorate (Goniewicz et al., 2025; Woraphong, 2025), including wetland ecosystems. Wetlands maintain hydrological balance, conserve biodiversity, absorb carbon, and support the socio-economic well-being of communities (Jeethu & Kaladevi, 2025; Mammen, 2025). However, more than 35% of the world's wetlands have been lost since 1970 due to human activities and land-use changes (Barry, 2025; Manu et al., 2025). Therefore, science education must instill creative and ethical character in wetland ecosystems (Morales et al., 2025). Wetland ecosystems can be a source of authentic and sustainable learning (Marcinkowski, 2025; Wang et al., 2025). In this case, students can connect science concepts (green chemistry) with real-life environmental problems (Sunday et al., 2025a; Vaz et al., 2025). For example, students use science concepts to explain water quality, pollution problems, and waste management in wetland ecosystems. Furthermore, the Freedom to Learn policy also encourages contextual, exploratory, and authentic problem-solving-based learning (Gunawan et al., 2025). Students are not only creative but also able to develop a sense of responsibility for maintaining environmental sustainability (Al-Barakat et al., 2025; Brahma, 2025).

In reality, science learning practices in schools still face various limitations. Science learning often focuses on delivering concepts and memorization, thus under-cultivating creative and ethical behavior in wetland ecosystems (Marcinkowski, 2025; Morales et al., 2025). This is reinforced by preliminary studies by researchers, which show that although students live in wetland ecosystems, they are rarely involved in problem-solving activities in their surroundings (Rahayu et al., 2025a). Furthermore, the principles of green chemistry have not been fully integrated into learning. As a result, students have difficulty connecting chemical concepts with conservation efforts in wetland ecosystems. Therefore, innovations in science learning are needed to integrate green chemistry while simultaneously fostering creative and ethical behavior in wetland ecosystems.

Several previous studies have shown that project-based learning integrated with green chemistry can improve students' creativity and environmental awareness (Hidayah et al., 2025; Rukoyah et al., 2025; Sunday et al., 2025b). However, these studies have primarily focused on cognitive outcomes and general environmental concern, while the integration of creative and ethical character as interconnected competencies remains underexplored. More importantly, previous studies have rarely examined how learning modules can facilitate meaningful learning by engaging students in sustained reflection, contextual problem-solving, and product-oriented activities rooted in authentic wetland issues. This creates both a pedagogical and empirical gap, because students may understand environmental concepts without necessarily internalizing ethical responsibility or translating ideas into creative actions. Although a valid and practical green chemistry module has been developed (Rahayu et al., 2025a), its effectiveness in fostering meaningful learning through the development of creative and ethical character has not yet been empirically tested. Therefore, this study addresses this gap by evaluating the effectiveness of the module in both limited and field implementation settings while examining not only character improvement but also the quality of student products as evidence of meaningful learning.

Based on the explanation above, the purpose of this study is to analyze the effectiveness of a PBL-based green chemistry module in enhancing students' creative and ethical character

in wetland ecosystems. The module is expected to serve as a structured learning guide, making the green chemistry learning process more systematic, contextual, and sustainable.

METHODS

This research is a development (R&D) study based on the ADDIE model (Kara & Atasoy, 2025). The objective of the study was to analyze the effectiveness of the green chemistry module in improving students' creative and moral character in wetland ecosystems. This study involved 48 high school students in Barito Kuala Regency, South Kalimantan; 15 were selected for a pilot trial, and 33 for an implementation trial. The research stages are shown in Figure 1.

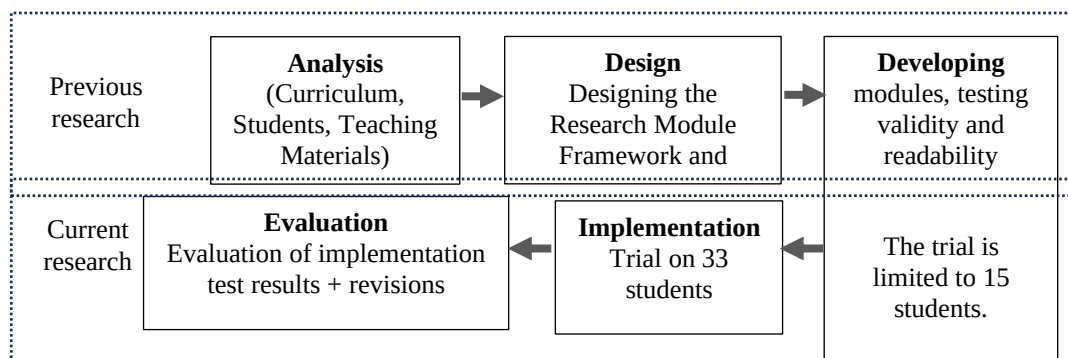


Figure 1 Research design and development of the green chemistry module

Previous research had conducted the ADD (Analysis, Design, and Development) phase. In the analysis phase, researchers examined the curriculum, student character, green chemistry material, and modules. In the design phase, learning objectives and outlines for the assessment instruments were developed. The next phase, the development phase, involved drafting the module, conducting validation tests by three science learning experts, and testing the module's readability. These three phases resulted in a PBL-based green chemistry module and a valid character questionnaire instrument, making it suitable for use in science learning (Rahayu et al., 2025a).

This research is a continuation of previous research conducted in the DIE (Development, Implementation, and Evaluation) phase. In the development phase, a limited pilot test of the module was conducted with 15 students using a one-group pretest-posttest design. The activity began with a pretest to assess students' initial creative and ethical attitudes towards wetland ecosystems. Next, the researchers implemented the PBL-based Green Chemistry module for three sessions. Finally, students were asked to complete a posttest using the same instrument as the pretest to determine changes in their character. In the implementation phase, a module trial was conducted in a real classroom involving 32 students. The same treatment was used as in the limited trial. During the evaluation phase, data analysis and revisions were conducted to produce a high-quality module.

This study used a creative and ethical character questionnaire as the primary instrument to measure changes in student character before and after learning. This instrument was designed based on indicators of creative and ethical character, namely understanding the interconnectedness of the Earth's ecosystem, preserving the natural environment, generating original ideas, producing original works and actions, and elaborating on various ideas. Before use, three science learning experts validated the instrument. The validation results showed scores for clarity (96.0), consistency (98.2), relevance (97.5), and language (93.5). Because all validity scores were above 85, the instrument was deemed valid and suitable for

use in this study. In addition to the questionnaire, researchers also collected data through assessments of student project results.

The research data was analyzed in stages. First, descriptive analysis was used to analyze the student character profile before and after learning based on percentage, average value, and achievement categories. Next, the researcher analyzed the increase in scores using the n-gain formula (Hake, 1998) that was shown in Tables 1 and 2.

Table 1 Criteria for character achievement

Score range	Category
81.25 – 100	Very good
71.50 – 81.25	Good
61.50 – 71.50	Moderate
43.75 – 62.50	Poor
0 – 43.75	Very poor

Table 2 N-Gain category

Score range	Category
> 0.70	High
0.30 – 0.70	Moderate
< 0.30	Low

Source: Hake (1998)

In addition, the researcher conducted inferential statistical analysis to test the significance of the difference in scores between the pretest and posttest. The test began with a normality test using the Shapiro–Wilk statistic and then continued with a paired-samples t-test that was used for normally distributed data, whereas the Wilcoxon test was used for non-normally distributed data, as shown in Table 3.

Table 3 Criteria of hypothesis testing

Data condition	Statistical test	Decision
Normal	Paired t-test	$p < 0.05$ significant
Non-normal	Wilcoxon	$p < 0.05$ significant

RESULTS AND DISCUSSION

The PBL-based green chemistry module is designed to support 21st-century science learning in line with the concept of deep learning. By integrating green chemistry principles and project activities in wetland ecosystems, students can learn more contextually, meaningfully, and sustainably (Sari & Saputro, 2025; Vaz et al., 2025; Wang et al., 2025). In line with previous research (Rahayu et al., 2025a), the developed green chemistry module consists of a cover page, foreword, module introduction, user instructions, table of contents, learning outcomes, concept maps, learning materials, daily assessments, reflections, a glossary, a bibliography, and an author profile (Rahayu et al., 2025a). Furthermore, Rahayu et al. reported that the module was valid and practical for training creative and moral character in the wetland context and recommended testing the model's effectiveness. Therefore, this study was conducted to determine the effectiveness of the module, as reflected in student character profiles before and after learning; the level of improvement; the significance of differences in pretest and posttest scores; and the results of student projects. The results of the analysis of students' creative and moral character profiles in the wetland ecosystem are presented in Figure 2.

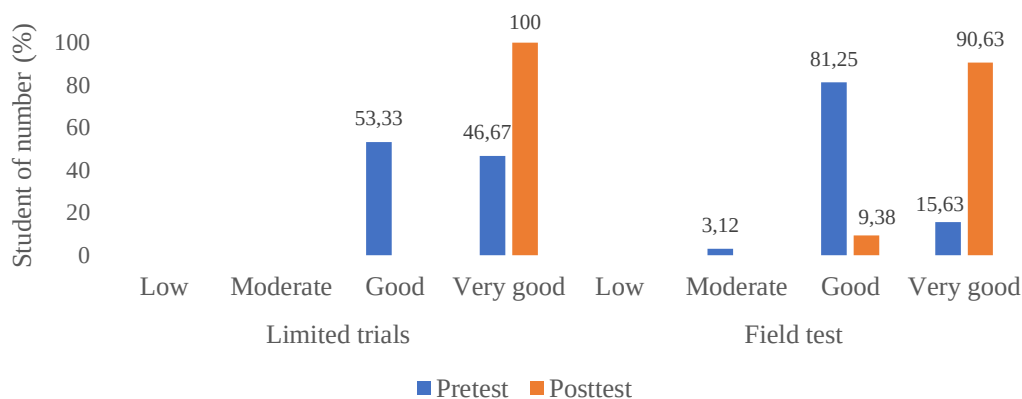


Figure 2 Profile of the creative and moral character of students

Figure 2 shows a consistent pattern of improvement: a shift in the distribution of character achievement from lower to higher categories. This is clearly visible in the limit trials, where students who were initially concentrated in the good and very good categories eventually shifted completely to the very good category. Likewise, in the field test, students who were initially predominantly in the good category (81.25%) then shifted to the very good category (90.63%). These results indicate that implementing a PBL-based green chemistry module can foster students' creative and moral character in wetland ecosystems. In this case, students engage in contextual learning by solving real-life problems (Gunawan, Atiqoh, et al., 2025; Vaz et al., 2025). The results of the pretest-posttest support these findings, as shown by the mean and n-gain analysis for each character indicator, as presented in Table 4.

Table 4 Mean pretest, posttest, and N-gain of students' creative and moral character

Group	Character Indicator	Pretest	Posttest	N-Gain
Limited trials	Understanding the interconnection of Earth's ecosystems	84.44 VG	92.78 VG	0.54 Moderate
	Preserving the natural environment	81.67 VG	91.67 VG	0.55 Moderate
	Generating original ideas	82.78 VG	91.11 VG	0.48 Moderate
	Producing original works and actions	82.78 VG	90.00 VG	0.42 Moderate
	Demonstrating flexible thinking in finding alternative solutions	82.08 VG	92.92 VG	0.60 Moderate
	Average	82.75 VG	91.69 VG	0.52 Moderate
Field test	Understanding the interconnection of Earth's ecosystems	77.53 G	84.34 VG	0.30 Moderate
	Preserving the natural environment	81.82 VG	90.40 VG	0.47 Moderate
	Generating original ideas	83.59 VG	93.43 VG	0.60 Moderate
	Producing original works and actions	83.59 VG	94.95 VG	0.69 Moderate
	Demonstrating flexible thinking in finding alternative solutions	82.58 VG	92.05 VG	0.54 Moderate
	Average	81.82 VG	91.04 VG	0.52 Moderate

Note: G = Good, VG = Very Good

Table 4 shows an improvement in student character before and after the green chemistry module was implemented. In limited trials, all indicators showed a relatively even pattern of improvement, with a moderate N-gain category. The ability to think flexibly in finding alternative solutions experienced the greatest improvement. Conversely, the ability to produce original work or actions showed the lowest improvement, although it remained in

the moderate category. In field tests, the ability to produce original ideas, work, or actions experienced the greatest improvement. Conversely, understanding the interconnectedness of Earth's ecosystems showed the lowest improvement, although it remained in the moderate category. Based on this pattern of improvement, the implementation of the PBL-based green chemistry module has been proven to improve student character in the moderate category. The greatest improvement was observed in the indicator of flexible thinking, specifically in the ability to find alternative solutions. In contrast, the lowest improvement occurred in the indicator of the ability to produce original work or actions, although it remained in the moderate category. Meanwhile, other indicators showed stable improvement, reflecting that project-based learning can strengthen various aspects of creative character and environmental awareness in a balanced manner. In the field test, the improvement pattern was almost the same as in the limited trials. The greatest improvement was in the indicators of the ability to produce original work or actions and the ability to generate original ideas. Conversely, the lowest improvement occurred in the indicator of understanding the interconnectedness of the Earth's ecosystem, although it remained in the moderate category. Based on this pattern, the PBL-based green chemistry model can be used to improve creative and ethical character in wetland ecosystems. These characters have developed along with mastery of green chemistry concepts and active involvement in wetland projects (Mashami et al., 2025; Rahayu et al., 2025b; Widyanoro et al., 2025). In line with constructivism theory, students have constructed their knowledge through involvement in wetland projects, scientific discussions, and scaffolding provided by teachers (Botes & Philip, 2025; Marcinkowski, 2025).

Next, to determine the significance of differences in student character before and after learning, an inferential statistical analysis was conducted. This analysis began with a Shapiro-Wilk normality test, and the results are presented in Table 5.

Table 5 Results of the Shapiro-Wilk test on student character

		Statistic	df	sig	Statistic test
Limited trials	Pretest	.970	15	.857	Paired sample t-test
	Posttest	.902	15	.103	
Field test	Pretest	.929	32	.037	Wilcoxon
	Posttest	.948	32	.127	

Based on Table 5, the results of the Shapiro-Wilk analysis show that all data are normally distributed ($p > 0.05$), except for the pretest data in the field test, which yielded $p < 0.05$, indicating the data are not normally distributed. Therefore, a paired-samples t-test will be conducted on the limited-trials data, and a Wilcoxon test will be conducted on the field-test data. The results of the paired sample test/Wilcoxon test are presented in Table 6.

Table 6 Results of paired sample t-test/Wilcoxon for all groups

	N	Paired t-test				Wilcoxon test		
		Mean	Std. Deviation	Std. error mean	t	df	p	z
Limited trials	15	-9.06	6.33	1.63	-5.53	14	<.001	
Field test	34							-4.864

In limited trials 1 ($N = 15$), the paired-samples t-test showed a mean of -9.062 ($t = -5.538$, $p < 0.001$), while in the field test, the Wilcoxon test showed $z = -4.864$ ($p < 0.001$). The p-values < 0.05 in both tests indicate that implementing the PBL-based green chemistry module significantly improves students' creative and moral character. This module

provides authentic, meaningful learning experiences through project-based activities in wetland ecosystems (Rahayu et al., 2025b).

In PBL, students develop creative and ethical character through the stages of identifying problems in wetlands, designing and implementing solutions, presenting project results, conducting evaluation and reflection, and revising project results (Hsu, 2025; Marcinkowski, 2025; Pereira et al., 2025). These activities encourage students to generate original ideas, create innovative works or actions, and think flexibly in finding alternative solutions (Ekayana et al., 2025; Yumarna et al., 2025; Yunita et al., 2025). In addition, students increase moral awareness and responsibility for the sustainability of wetland ecosystems and utilize them for the common good (Morales et al., 2025; Marcinkowski, 2025). Thus, the implementation of PBL not only improves mastery of chemical concepts but also develops character traits relevant to real life (Al-Qoyyim & Kurniawan, 2025; Ulfah & Hidayah, 2025). This finding aligns with Piaget's theory of moral development. Various real-life activities, such as wetland observations, conservation projects, waste processing, and the manufacture of environmentally friendly products, can foster students' moral awareness. The success of the green chemistry module in developing students' creative and moral characters is also reinforced by the analysis of student products, as presented in Table 7.

Table 7 Students' product learning outcomes

Assessment Aspects	Limited Trials		Field Test	
	Value	Category	Value	Category
Creativity and Innovation	82.21	Very good	78.91	Good
Content Accuracy	82.21	Very good	78.00	Good
Organization and Structure of Material	85.00	Very good	79.00	Good
Language Use	75.00	Good	89.06	Very good
Aesthetic Value and Attractiveness	83.22	Very good	89.62	Very good
Average Score	81.52	Very good	82.92	Very good

Based on Table 7, students have produced products of very good quality. In limited trials, the indicators of creativity, content accuracy, and material organization reached the very good category; in the field test, the indicators of language use and product aesthetic value reached the very good category, while the other indicators were in the good category. This pattern indicates that PBL promotes overall product quality despite differences in strengths in certain aspects. The contribution of the module to enhancing students' creative and ethical character can be explained by the way learning activities were structured. The module does not position projects merely as assignments but as a process that integrates contextual inquiry, collaborative problem-solving, reflective evaluation, and environmentally responsible action. Through this process, students were encouraged to transform conceptual understanding into creative solutions while considering the ethical implications of their decisions. This reflects principles of social constructivism and experiential learning, where character development emerges through authentic participation, reflection, and repeated practice. Thus, the improvement observed in this study is not only associated with project completion but also with the module structure that systematically supports the internalization of creative and ethical character.

PBL activities (such as wetland ecosystem observation, solution design and implementation, presentation, and evaluation-reflection) enable students to actively construct knowledge, develop creativity, and instill moral values for the environment (Al-Qoyyim & Kurniawan, 2025; Fauzi et al., 2025; Purwanti et al., 2025). These findings support the principles of Vygotsky's constructivism and experiential learning (Gannar &

Kilani, 2025; Wiyono et al., 2025) and are in line with previous research (Gunawan, Kosim, et al., 2025; Pratama et al., 2025; Sánchez-García & Reyes-de-Cózar, 2025) that PBL improves students' ability to produce creative, structured, and aesthetically valuable work through collaborative processes and feedback. Thus, the PBL-based green chemistry module not only improves students' mastery of chemical concepts and creative-moral character but also enables them to produce creative products. Some of the students' creative products are shown in Figure 3.



Figure 3 Various student product learning outcomes (such as posters and miniatures)

This study still has several limitations, namely a small sample size, a study location limited to one school, and a relatively short implementation time. This means that this study does not fully describe the long-term development of student character. Nevertheless, the study provides fundamental implications for the development of contextual science education through the integration of creative and ethical character in wetland ecosystems. The integration of green chemistry and character principles in PBL provides authentic learning experiences in the context of wetland ecosystems (Rahayu et al., 2025b; Widyanoro et al., 2025). This approach also provides opportunities to develop other 21st-century competencies, enabling teachers and curriculum developers to use it as an alternative, relevant learning strategy.

CONCLUSION

The PBL-based green chemistry module has proven effective in fostering creative and ethical character in students within the context of wetland ecosystems. Descriptively, students' character profiles, initially dominated by the good category, shifted to the excellent category. Furthermore, this study demonstrated a significant improvement in student character, resulting in student work in the excellent category. Through this module, students integrated creative and ethical character into project activities related to wetland ecosystems. This activity encouraged students to increase their moral awareness and responsibility in maintaining and preserving the surrounding wetland environment. To strengthen the generalizability of the research findings, further studies are recommended that involve a broader sample from multiple institutions and a larger number of participants. Furthermore, further research should develop more contextually relevant and applicable learning projects to better align with students' daily lives.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

For research articles with multiple authors. SS has contributed to the section of conceptualization, methodology, project administration, supervision, original draft preparation, and corresponding author. QQ and SS. have contributed to data curation, formal analysis, and writing as reviewers and editors. MM, SR, and NFAR. have contributed to the methodology and to writing in the review and editing. SS has contributed to the review and editing.

AI DISCLOSURE STATEMENT

The authors used Grammarly during the preparation of this work to check and correct the grammar used in this article. After using the tool/service, the authors thoroughly reviewed and edited the content as needed and take full responsibility for the publication's content. The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

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