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THE EFFECT OF PjBL-STEM INTEGRATED WITH GREEN CHEMISTRY PRINCIPLES ON ENHANCING CREATIVE THINKING SKILLS AND ENVIRONMENTAL LITERACY

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Abstract: The demands of 21st-century competition require several fundamental competencies, one of which is creativity. Additionally, the affective domain, particularly environmental awareness, has received increasing international attention. This study aims to examine the effect of implementing PjBL-STEM integrated with green chemistry principles in enhancing students' creative thinking skills and environmental literacy. The research employed a quasi-experimental design with a nonequivalent control group approach involving 10th-grade students at SMAN 1 Baitussalam. Class X IPAS 1 served as the experimental group, whereas Class X IPAS 2 served as the control group. The research instruments included validated learning material evaluation sheets, creative thinking skills test items, and environmental literacy comprehension tests, all of which were reviewed by experts and analyzed empirically. The data analysis techniques involved N-Gain tests and independent sample t tests with a significance level of 0.05. The hypothesis testing results revealed significant N-Gain scores for both creative thinking skills and environmental literacy ($p < 0.001$). These findings indicate a significant difference in the improvement of creative thinking skills and environmental literacy understanding between the experimental and control groups following the implementation of the PjBL-STEM model integrated with green chemistry principles.

Keywords: PjBL-STEM, green chemistry, creative thinking skills, environmental literacy

Abstrak: Persaingan abad 21 menuntut beberapa kemampuan fundamental salah satunya adalah *creativity*. Selain itu, aspek afektif juga sedang mendapat perhatian dari dunia internasional terkait kesadaran terhadap lingkungan. Penelitian ini bertujuan mengkaji pengaruh penerapan PjBL-STEM terintegrasi prinsip *green chemistry* dalam meningkatan keterampilan berpikir kreatif dan literasi lingkungan peserta didik. Jenis penelitian ini adalah *quasi* eksperimen dengan desain penelitian *nonequivalent control group design.* Populasi penelitian adalah siswa kelas X SMAN 1 Baitussalam dengan kelas X IPAS 1 sebagai kelas eksperimen dan kelas X IPAS 2 sebagai kelas kontrol. Instrumen dalam penelitian ini yaitu lembar validasi perangkat pembelajaran, soal tes keterampilan berpikir kreatif dan tes pemahaman literasi lingkungan yang divalidasi oleh pakar dan analisis secara empiris. Teknik pengolahan data menggunakan uji N-Gain dan uji *independent sample test* dengan taraf signifikan 0,05. Hasil pengujian hipotesis menunjukkan signifikansi data N-gain untuk keterampilan berpikir kreatif dan literasi lingkungan sebesar sig. (0,000) < (0,05). Hasil tersebut menunjukkan bahwa, terdapat perbedaan signifikan terhadap peningkatan keterampilan berpikir kreatif dan pemahaman literasi lingkungan antara kelas eksperimen dengan kelas kontrol setelah penerapan model PjBL-STEM terintegrasi prinsip *green chemistry.*

Kata kunci: PjBL-STEM, *green chemistry*, keterampilan berpikir kreatif, literasi lingkungan

INTRODUCTION

The competition in the 21st-century global era demands several fundamental competencies that students must possess, known as the '4Cs': critical thinking, communication, collaboration, and creativity (Khoiri et al., 2021; Saimon et al., 2023). The evidence indicates that creative thinking skills are essential to keep pace with ongoing changes, requiring learners to think outside conventional frameworks to generate innovative ideas (Widana & Septiari, 2021).

According to the results reported by the Programme for International Student Assessment (PISA) 2022, 69% of students in Indonesia possess creative thinking skills at a low proficiency level (OECD, 2024). This finding aligns with prior research by Madyani et al. (2020), which demonstrated that among 126 students, the distributions of creative thinking skills across high, medium, and low categories were 17.46%, 36.51%, and 46.03%, respectively. Furthermore, studies by Astuti et al. (2020) and Qomariyah & Subekti, (2021) also indicate that the average achievement across all indicators of students' creative thinking remains in need of improvement.

Moreover, the affective domain is receiving increasing international attention, particularly with respect to environmental awareness, which is recognized as a core competency in achieving sustainable development goals (SDGs) (Fauziyah & Hamdu, 2021). Environmental literacy, as an affective aspect, plays a crucial role in science and other disciplines by enhancing the understanding and awareness of environmental issues (Kaya & Elster, 2019; Masruroh et al., 2024; Vijaykumar et al., 2021). Notably, UNESCO has urged that environmental education be integrated as a core component of global curricula by 2025 (Lovren & Jablanovic, 2023).

A study by Parwati et al. (2021) revealed that environmental literacy among 140 high school students in Bali, categorized by gender, remained at a low level, with no significant difference between male and female students. These findings are supported by research from

Nursa'adah et al. (2021) and Gabriella & Sugiarto (2020), which similarly indicated that students' environmental literacy generally falls within the moderate category, with some indicators even registering at low levels.

Preliminary observations conducted at SMAN 1 Baitussalam revealed that the research focused on green chemistry, a newly introduced topic in the high school chemistry curriculum under the Merdeka curriculum (Maulidiningsih et al., 2023; Ratnawati & Praptomo, 2023). The interview results indicated that teachers still employ conventional methods when delivering green chemistry content and have yet to utilize teaching materials such as student worksheets (LKPDs), modules, or similar resources. Consequently, it has led to one-directional learning experiences with unsystematic and unengaging material presentation, making it challenging for students to grasp concepts (Said et al., 2025). This situation is particularly regrettable given that the subject matter can significantly influence pro-environmental behaviors and is closely tied to sustainable environmental preservation efforts (Ghazali & Yahaya, 2022; Zhang et al., 2021).

This issue necessitates the development of innovative learning approaches. An effective and efficient learning process requires appropriate instructional strategies (Khefrianti et al., 2024). One innovative learning model is project-based learning (PjBL), which is integrated with science, technology, engineering, and mathematics (STEM). Previous research findings have demonstrated that the implementation of PjBL-STEM effectively enhances students' creativity while significantly improving their conceptual understanding (Mamahit et al., 2020; Hanif et al., 2019).

Existing studies on PjBL-STEM implementation have not incorporated affective domain evaluation, which is crucial for achieving sustainable development goals. Therefore, this research integrates green chemistry principles into chemistry education through project-based learning with a STEM approach. Sudarmin et al. (2019) concluded that green chemistry-integrated learning effectively enhances students' conceptual thinking skills while fostering conservation-oriented character development.

The green chemistry principles integrated into the PjBL-STEM model include three key tenets: prevention, less hazardous chemical synthesis, and the use of renewable feedstocks, which are selected based on instructional content. This application of green chemistry principles can serve as an effective strategy for significantly enhancing students' attitudinal and behavioral aspects of environmental literacy (Dewi & Listyarini 2022; Zidny & Eilks 2022). Consequently, the interconnected integration of green chemistry principles within the PjBL-STEM learning model drives curriculum innovation to improve students' creative thinking skills and environmental literacy.

METHOD

This study employs an experimental research approach with a quasi-experimental design with a model nonequivalent control group design. The complete research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_3	X_2	O_4

This research was conducted at State Senior High School 1 Baitussalam during the 2024–2025 academic year and involved a population of 155 tenth-grade students. A purposive sampling technique was employed based on students' initial cognitive abilities, which were assessed through a standardized test administered to all tenth-grade classes. From this population, two classes were selected as research samples: X IPAS 1 and X IPAS 2. The experimental group (X IPAS 1) received instruction using a PjBL-STEM approach incorporating green chemistry principles, whereas the control group (X IPAS 2) was taught using conventional lecture-based methods. This research design allowed for a comparative analysis of the effectiveness of these distinct pedagogical approaches.

The independent variables in this study include the green chemistry-integrated PjBL-STEM learning model and the conventional lecture-based teaching method. The PjBL-STEM framework follows the five-phase model developed by Laboy-Rush (2010): reflection, research, discovery, application, and communication. The integration of green chemistry principles into this model incorporates three fundamental tenets: prevention, less hazardous chemical processes, and the use of renewable feedstocks. The dependent variable focuses on creative thinking skills, operationalized through four key indicators adapted from (Astuti et al., 2020): fluency, elaboration, flexibility, and originality. Additionally, environmental literacy serves as another dependent variable, measured across four domains as proposed by Hollweg et al. (2011): environmental knowledge, cognitive skills, attitudes, and behavioral dispositions.

Creative thinking skills were assessed via constructed-response test instruments with essay questions designed to measure each indicator (Torrance & Aliotti, 1969). The evaluation criteria for the percentages of creative thinking skills were determined with reference to Table 2.

Table 2. Criteria for Creative Thinking Skills

Creative Thinking Skills (%)	Category
81 - 100	Very Creative
61 - 80	Creative
41 – 60	Quite Creative
21 – 40	Less Creative
0 – 20	Not Creative

Environmental literacy was measured using the Middle School Environmental Literacy Instrument (MSELI), which was originally developed by McBeth et al. (2008) and subsequently adapted to meet the study's specific requirements. The scoring range and corresponding levels of environmental literacy were interpreted based on the criteria outlined in Table 3.

Table 3. Range of scores and levels of environmental literacy

Environmental Literacy Domain	Category		
	Low	Moderate	High
Knowledge	0 - 20	21 - 40	41 - 60
Cognitif Skills	0 - 20	21 - 40	41 - 60
Attitude	12 - 27	28 - 44	45 - 60
Behavior	12 - 27	28 - 44	45 - 60
Environmental Literacy Composite Score	24 - 96	97 - 168	169 -240

The research instruments were validated by two experts before being tested with students. The experts' evaluation confirmed that both measurement tools were suitable for use. In the empirical testing, there were 4 valid essay questions for assessing creative thinking skills, with a reliability score of 0.8. For the environmental literacy instrument, 20 valid multiple-choice questions were obtained with a reliability of 0.96, along with 30 questionnaires that met the criterion of being highly suitable.

The data analysis technique employs descriptive statistics and hypothesis testing. Descriptive statistics include pretest, posttest, and N-Gain results from both classes. Hypothesis testing uses parametric and nonparametric statistical tests, specifically the independent sample t test and Mann–Whitney test. Prior to these analyses, normality and homogeneity tests were conducted using the Shapiro–Wilk test and Levene's test, respectively. These preliminary tests were performed to verify the normal data distribution and variance homogeneity.

RESULTS AND DISCUSSION

This research aims to examine the effects of implementing green chemistry principle-integrated PjBL-STEM in enhancing students' creative thinking skills and understanding of environmental literacy in green chemistry. The research was conducted over two sessions for both the experimental and control classes, with sample sizes of 23 and 22 students, respectively.

The PjBL-STEM model combined with green chemistry principles follows the constructivist learning approach (Efgivia et al., 2021). In this method, students actively build their own knowledge while teachers guide the learning process. Students work together in groups to complete LKPD, share ideas, remain motivated, and take joint responsibility for their work (Fedeli & Vardanega, 2019; Loes, 2019; Mamahit et al., 2020).

The PjBL-STEM process involves several key steps: gathering information, answering questions, planning actions, applying knowledge, and communicating project results. The STEM approach follows the engineering design process (EDP), guiding students to develop solutions through questioning, imagining, planning, creating, and improving. Green chemistry principles serve as the foundational concept driving these solutions. Students are required to create final products that meet three green chemistry principles outlined in their LKPD: prevention, the use of nonhazardous substances, and the utilization of renewable materials.

The results of the students' creative thinking skills and environmental literacy were measured through pretests and posttests. The collected data were then analyzed using N-Gain to measure learning improvements. Hypothesis testing employed independent sample t tests to identify significant differences in the dependent variables between the experimental and control groups after the treatment. Prior to this, normality testing was conducted on the creative thinking skills data using the Shapiro–Wilk test, with the results presented in Table 4.

Table 4. Normality Test

Variable	Experimental			Control		
	Pretest	Posttest	N-Gain	Pretest	Posttest	N-Gain
Creative thinking skills	0.180	0.100	0.056	0.181	0.551	0.011
Environmental literacy	0.819	0.856	0.559	0.477	0.906	0.735

Table 4 shows that the pretest, posttest, and N-Gain environmental literacy data from both classes had a sig. (2-tailed) > 0.05, indicating normally distributed data. However, the N-Gain data for creative thinking skills in the control class were not normally distributed. Therefore, hypothesis testing was conducted using the nonparametric Mann–Whitney test. Additionally, homogeneity testing was performed using Levene's test, as shown in Table 5, to determine whether the sample data came from populations with equal variances.

Table 5. Homogeneity Test

Levene's test	Pretest	Posttest	N-Gain
Creative thinking skills	0.508	0.012	0.563
Environmental literacy	0.036	0.132	0.139

Table 5 reveals that the posttest data for creative thinking skills and the pretest data for environmental literacy showed nonhomogeneous variances (sig. < 0.05). Nevertheless, the independent samples t test could still be performed because the data were normally distributed. The hypothesis test results for creative thinking skills and environmental literacy are presented in Table 6.

Table 6. Hypothesis Test

Variable	Data	Independent sample t test	Mann whithney U
Creative thinking skills	Pretest	0.470	-
	Posttest	0.000	-
	N-Gain	-	0.000
Environmental literacy	Pretest	0.860	-
	Posttest	0.000	-
	N-Gain	0.000	-

As shown in Table 6, the pretest data for both measured variables presented significance values (2-tailed) > 0.05; therefore, the null hypothesis (H_0) was accepted. In conclusion, there was no significant initial difference in creative thinking skills or environmental literacy between the experimental and control groups. However, the posttest data analysis for both variables revealed significance values (2-tailed) < 0.05, indicating that H_0 was rejected and that the alternative hypothesis (H_a) was accepted. Consequently, the results demonstrate a significant difference in creative thinking skills and environmental literacy between the experimental group using PjBL-STEM integrated with green chemistry principles and the control group using conventional lecture-based methods.

The final hypothesis testing was conducted on the N-Gain data to examine differences in the improvement of the two studied variables. According to Table 6, the N-Gain data for creative thinking skills were analyzed using the nonparametric

Mann–Whitney test, which revealed a significance value (2-tailed) < 0.05. Consequently, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_a) was accepted. In conclusion, there was a significant difference in the improvement in students' creative thinking skills between the experimental group that received the green chemistry-integrated PjBL-STEM model and the control group that used conventional teaching methods. Moreover, the N-Gain data for environmental literacy were tested using an independent sample t test, which yielded a significance value (2-tailed) < 0.05, indicating that H_0 was rejected. Therefore, Ha concluded that there was a significant difference between the experimental class after the implementation of the PjBL-STEM model integrated with green chemistry principles and the control class when conventional methods were used to improve students' environmental literacy.

Creative Thinking Skills

The improvement in students' creative thinking skills was assessed by comparing the pretest and posttest scores between the two classes. The results of the pretest–posttest score analysis can be seen in Table 7.

Table 7. Creative Thinking Skills Scores

Creative Thinking Skills Indicator	Experimental			Control		
	Pretest	Posttest	N-Gain	Pretest	Posttest	N-Gain
Fluency	35.87	81.52	0.70	11.36	13.64	0.03
Flexibility	39.13	94.57	0.90	38.63	82.95	0.75
Originality	7.61	93.48	0.93	5.68	28.41	0.25
Elaboration	11.96	75	0.73	26.13	30.68	0.05
Average score	23.64	86.14	0.833	20.45	38.92	0.241

According to Table 7, the experimental class achieved an average N-Gain score greater than 0.7, indicating a high level of improvement in students' creative thinking skills. In contrast, the control class obtained an N-Gain score below 0.3, which falls into the low improvement category. These results demonstrate that creative thinking skills can be effectively developed through teaching practices that shift from conventional instruction to student-centered learning approaches (Asiri, 2020).

In contrast, the control class results in Table 7 demonstrate that conventional lecture-based instruction remained less effective. This finding aligns with Ritter et al. (2020), who reported that traditional teaching strategies fail to adequately support either teachers or students in developing creative thinking skills and achieving optimal academic outcomes.

The improvement in creative thinking skills can be observed through the enhancement of each individual indicator. According to Table 7, the fluency indicator had an N-Gain score of 0.70 for the experimental class, which falls into the medium category. This finding demonstrates that the PjBL-STEM model integrated with green chemistry principles significantly influences students' fluency in responding to questions. The project-based STEM approach enables students to synthesize their knowledge by incorporating technology, engineering, and mathematics when formulating their answers, thereby fulfilling the fluency indicator criteria (Iskandar et al., 2020; Widyasmah et al., 2020).

In contrast, the control class achieved a significantly lower N-Gain score of only 0.03, falling into the low improvement category. This result indicates that the conventional teaching method failed to enhance students' fluency. The data suggests that students continue to experience difficulties in articulating their ideas effectively (Pramesti et al., 2022).

For the flexibility indicator, the experimental class achieved an N-Gain score of 0.90 (high category), whereas the control class scored 0.75 (medium category). Although both instructional approaches improved students' flexibility, the experimental class employing the green chemistry-integrated PjBL-STEM model demonstrated significantly better outcomes. The project required students to design infographics about alternative fuels by interpreting concepts through diverse approaches. These findings align with those of Rinto et al. (2022), who showed that STEM-based project learning enhances thinking flexibility by developing conceptual understanding through experimental activities, project creation, and presentations.

The originality indicator reflects the ability to generate and combine novel ideas (Somwaeng, 2021). The experimental class showed significant improvement in this indicator, with an N-gain score of 0.93 (high category), whereas the control class achieved only 0.25 (low category). The green chemistry-integrated PjBL-STEM model requires students to develop innovative ideas when creating infographics about alternative fuels. This constructivist-based learning approach effectively enhances students' originality in generating unique solutions to problems (Khalil et al., 2023; Yustina et al., 2021).

The elaboration indicator reflects students' ability to develop ideas in detail by incorporating facts, expanding concepts, and creatively applying new ideas (Ernawati et al., 2019; Ng & Lee, 2019; Terhemba et al., 2023). As shown in Table 7, the experimental class demonstrated moderate improvement in this indicator, with an N-Gain score of 0.73 following the intervention. These findings align with those of Ani et al. (2024), who showed that PjBL-STEM learning effectively enhances students' elaboration skills by providing opportunities to explore and express their ideas more thoroughly.

In contrast, the control class showed almost no improvement, with an N-Gain score of only 0.05 (low category). This was evident from the students' responses, which lacked detailed conceptual connections and demonstrated difficulty in linking different concepts. These findings support Widyasmah et al. (2020), who concluded that students who fail to provide sufficiently detailed explanations have not fully met the elaboration criteria.

Environmental literacy

Environmental literacy improvement was measured across four domains: knowledge, cognitive skills, attitudes, and student behaviors. The analysis yielded average pretest, posttest, and N-Gain scores for environmental literacy in both the experimental and control classes, as presented in Table 8.

Table 8. Environmental literacy scores

Environmental Literacy Domain	Experimental			Control		
	Pretest	Posttest	N-Gain	Pretest	Posttest	N-Gain
Knowledge	26.08	54.00	0.84	28.36	36.54	0.30
Cognitif Skills	15.37	52.92	0.85	17.20	29.78	0.30
Attitude	40.72	53.17	0.65	39.60	48.64	0.44
Behavior	37.67	54.28	0.76	33.92	45.96	0.44
Composite Score	119.84	214.37	0.79	119.10	160.93	0.35

The analysis results in Table 8 demonstrate improved environmental literacy among students in both classes. However, the experimental class showed significantly greater improvement than did the control class, as evidenced by average N-gain scores of 0.79 (experimental) and 0.35 (control). These findings align with those of Muganga & Ssenkusu (2019), who reported that conventional teacher-centered approaches often fail to achieve the desired learning outcomes.

The PjBL approach implemented in the experimental class enhanced students' problem-solving, creative thinking, collaboration, and communication skills, with teachers serving as learning facilitators (Hira & Anderson, 2021;

Maulana, 2020; Taskiran, 2021). Student groups worked with PjBL-STEM worksheets, integrating green chemistry principles and following an EDP framework. Their project involved creating educational infographics about alternative fuel sources to replace petroleum.

The infographic projects were designed to incorporate three essential green chemistry principles from the worksheets: prevention, use of renewable feedstocks, and less hazardous processes. This integration of green chemistry principles fundamentally shifted students' perceptions of chemistry, highlighting its role in sustainability and environmental protection (Blatti et al., 2019; Hurst et al., 2023; Paschalidou et al., 2022). These principles and practices promote the efficient use of resources, reduce or eliminate harmful substances, and prioritize human health and environmental sustainability (Pertiwi & Wahyuningrum, 2024). Through this approach, students developed enhanced abilities to identify environmental issues, increased ecological awareness, and greater motivation to participate in solving environmental problems.

The improvement in each domain of environmental literacy was analyzed to assess the extent of students' progress. The knowledge domain, which is related to ecological understanding, increased in both groups: the experimental class achieved an average N-gain of 0.84, whereas the control class presented a lower average N-gain of 0.30 (Table 8). These results indicate that the conventional teaching model used in the control group provided only limited and overly general knowledge, failing to adequately engage or motivate students in their environmental learning.

The instructional model implemented in the experimental class guided the students through systematic problem reflection as part of the PjBL-STEM process. This STEM approach using EDP enables students to identify environmental issues, define solution parameters, and apply the green chemistry prevention principle. This methodology fostered a fundamental paradigm shift from pollution control to pollution prevention (Tiwari et al., 2022). Students actively internalize environmental knowledge and develop responsible ecological dispositions (Amoah & Addoah, 2021).

The cognitive skills domain comprises three indicators: problem identification, problem analysis, and action planning. Both classes improved in this domain. As shown in Table 8, the experimental class achieved an average N-gain above 0.7 (classified as high), whereas the control class had a lower gain of 0.3.

Students in the experimental group developed conceptual understanding by actively seeking relevant references and gathering information during the research phase of PjBL-STEM. The EDP guided them to exchange ideas and collaborate on prevention strategies. In contrast, the control group lacked hands-on learning experiences with the environmental issues being studied (I'liyin, 2023; Santoso et al., 2021). The instruction was confined to textbook-based classroom learning and teacher-delivered content (Rokhmah et al., 2021).

Measurement of the attitude domain, which comprises three indicators—verbal commitment, environmental sensitivity, and environmental feelings—showed comparable improvements across the two classes. According to Table 8, the average N-gain for both groups was less than 0.7, which was classified as moderate. This finding is noteworthy, as both classes achieved similar levels of improvement in the attitude domain. Students' psychological attitudes toward the environment are believed to influence their willingness to acknowledge and adopt value-based perspectives on environmental issues (Hollweg et al., 2011). However, emotional involvement and entrenched social norms render these attitudes relatively stable and resistant to short-term change (Hines et al., 1987; Krathwohl et al., 1964).

Despite the moderate gains in both groups, Table 8 reveals that the green chemistry-integrated PjBL-STEM approach yielded better attitude domain outcomes than the conventional method. The learning process fostered collaboration and habits of mind within groups, aligning with the discovery phase of PjBL-STEM. During this stage, the EDP guided students in designing products while adhering to the less hazardous principle, prioritizing chemical processes with minimal environmental health risks. This product or process design approach aims to reduce the use and generation of hazardous substances in principle of green chemistry (Oliveira et al., 2024).

The behavioral domain was the final aspect measured in the environmental literacy assessment, as its indicators reflect the tangible outcomes of the other three domains. According to Table 8, the experimental class showed a more significant improvement in behavioral outcomes than did the control class, with an average N-Gain score of 0.76 classified as high. This progress stems from the PjBL-STEM approach, where students apply their ideas as solutions and present their findings, reinforcing the application and communication phases. Additionally, the EDP guides students in developing products based on their designs, evaluating their effectiveness, and refining them through analysis and discussion.

The creation of infographics aims to educate the public on the use of renewable raw materials, serving as an act of environmentally responsible behavior. The application of green chemistry principles seeks to examine how this integration can positively influence environmental behavior (Oliveira et al., 2024). Research by Yildirim et al. (2025) highlights the importance of environmental literacy in promoting eco-friendly practices and reducing negative environmental impacts. Students with strong environmental literacy demonstrate responsible environmental behavior as a tangible outcome of the other three domains (Febriasari & Supriatna, 2017). During the learning process, students acquire environmental knowledge through project-based tasks that enhance their cognitive skills in identifying and developing sensitivity toward environmental issues. As a result, they become capable of determining concrete actions as solutions to the problems presented in their project assignments.

CONCLUSION

The findings revealed statistically significant N-gain scores for both creative thinking skills and environmental literacy ($p < 0.001$). These results demonstrate a significant difference between the experimental group and the control group after the implementation of the PjBL-STEM model integrated with green chemistry principles to enhance students' creative thinking ability and environmental literacy. This study provides a valuable foundation for future research, suggesting (1) direct implementation of all twelve green chemistry principles and (2) incorporation of more specialized assessment instruments.

REFERENCES

Amoah, A., & Addoah, T. (2021). Does environmental knowledge drive pro-environmental behaviour in developing countries? evidence from households in ghana. *Environment, Development and Sustainability*, *23*(2), 2719–2738. https://doi.org/10.1007/s10668-020-00698-x

Ani, S. R. P. D., Parmin, & Wh, N. (2024). Enhancing elaboration skills through integrated stem-pjbl: a study on object movement and living creatures. *JISE*, *13*(2), 74–82. https://journal.unnes.ac.id/journals/jise/

Asiri, A. A. (2020). The effectiveness of the inquiry and brain storming strategies in developing achievement and creative thinking skills in arabic language of university students. *International Journal of English Linguistics*, *11*(1), 253. https://doi.org/10.5539/ijel.v11n1p253

Astuti, Waluya, S. B., & Asikin, M. (2020). The important of creative thinking ability in elementary school students for 4.0 era. *International Journal on Education, Management and Innovation (IJEMI)*, *1*(1), 207-213. http://journal2.uad.ac.id/index.php/ijemi

Blatti, J. L., Garcia, J., Cave, D., Monge, F., Cuccinello, A., Portillo, J., Juarez, B., Chan, E., & Schwebel, F. (2019). Systems thinking in science education and outreach toward a sustainable future. *Journal of Chemical Education*, *96*(12), 2852–2862. https://doi.org/10.1021/acs.jchemed.9b00318

Dewi, N. K., & Listyarini*, R. V. (2022). Development of green chemistry-based practicum module for senior high school to promote students' environmental literacy. *Jurnal Pendidikan Sains Indonesia*, *10*(3), 641–653. https://doi.org/10.24815/jpsi.v10i3.25163

Efgivia, M. G., Suryani, Rinanda, A. R., Hidayat, A., Maulana, I., & Budiarjo, A. (2021). Analysis of constructivism learning theory. *Proceedings of the 1st UMGESHIC International Seminar on Health, Social Science and Humanities (UMGESHIC-ISHSSH 2020)*, 208–212. http://repo.iain-tulungagung.ac.id

Fauziyah, S. N., & Hamdu, G. (2021). Analisis item instrumen pengukur kompetensi berpikir kritis siswa berbasis esd di sekolah dasar. *Indonesian Journal of Social Science Education (IJSSE)*, *3*(1), 55–64. http://ejournal.iainbengkulu.ac.id/index.php/ijsse

Febriasari, L. K., & Supriatna, N. (2017). Enhance environmental literacy through problem based learning. *Journal of Physics: Conference Series*, *895*(1). https://doi.org/10.1088/1742-6596/895/1/012163

Fedeli, M., & Vardanega, T. (2019). Enhancing active learning and fostering employability: the experience of a two-stage capstone project at the university of padova. *New Directions for Adult and Continuing Education*, *2019*(163), 25–35. https://doi.org/10.1002/ace.20339

Gabriella, D. A., & Sugiarto, A. (2020). Kesadaran dan perilaku ramah lingkungan mahasiswa di kampus. *Jurnal Ilmu Sosial Dan Humaniora*, *9*(2), 260. https://doi.org/10.23887/jish-undiksha.v9i2.21061

Ghazali, M. Z., & Yahaya, A. (2022). Analysis of green chemistry knowledge, awareness and practice among the university students. *Journal of Science and Mathematics Letters*, *10*(1), 79–90. https://doi.org/10.37134/jsml.vol10.1.8.2022

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing students' creativity through stem project-based learning. *Journal of Science Learning*, *2*(2), 50–57. https://doi.org/10.17509/jsl.v2i2.13271

Hines, J. M., Hungerford, H. R., & Tomera, A. N. (1987). Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education*, *18*(2), 1–8. https://doi.org/10.1080/00958964.1987.9943482

Hira, A., & Anderson, E. (2021). Motivating online learning through project-based learning during the 2020 covid-19 pandemic. *IAFOR Journal of Education*, *9*(2), 93-99.

Hollweg, K. S., Taylor, Bybee, J. R., Marcinkowski, R. W., Mcbeth, T. J., & Zoido, W. C. (2011). *Developing a Framework for Assessing Environmental Literacy*. http://www.naaee.net.

Hurst, K. F., Sintov, N. D., & Donnelly, G. E. (2023). Increasing sustainable behavior through conversation. *Journal of Environmental Psychology*, *86,* 6245-6321. https://doi.org/10.1016/j.jenvp.2022.101948

I'liyin, Y. J. (2023). Analisis enviromental literacy dan hasil belajar kognitif peserta didik pada pelajaran geografi di madrasah aliyah. *Journal of Geography Education*, *4*(1), 11–16. http://jurnal.unsil.ac.id/index.php/geoducation

Iskandar, I., Sastradika, D., Jumadi, Pujianto, & Defrianti, D. (2020). Development of creative thinking skills through STEM-based instruction in senior high school student. *Journal of Physics: Conference Series*, *1567*(4). https://doi.org/10.1088/1742-6596/1567/4/042043

Kaya, V. H., & Elster, D. (2019). A critical consideration of environmental literacy: Concepts, contexts, and competencies. *Sustainability (Switzerland)*, *11*(6). https://doi.org/10.3390/su11061581

Khalil, R. Y., Tairab, H., Qablan, A., Alarabi, K., & Mansour, Y. (2023). STEM-based curriculum and creative thinking in high school students. *Education Sciences*, *13*(12), 1-15. https://doi.org/10.3390/educsci13121195

Khefrianti, S., Rustaman, N., Kadarohman, A., & Wiji, W. (2024). Exploring chemistry teachers' awareness of fablab for transformative educational practices. *EduChemia: Jurnal Kimia Dan Pendidikan*, *9*(2), 188-193. https://doi.org/10.30870/educhemia.v9i2.24418

Khoiri, A., Evalina, Komariah, N., Utami, R. T., Paramarta, V., Siswandi, Janudin, & Sunarsi, D. (2021). 4Cs analysis of 21st century skills-based school areas. *Journal of Physics: Conference Series*, *1764*(1). https://doi.org/10.1088/1742-6596/1764/1/012142

Krathwohl, D. R., Bloom, Benjamin. S., & Masia, Bertram. B. (1964). *Taxonomy of educational objectives: The classification of educational goals, Hand book II: Affective domain*. David Mckay Company In corporated.

Laboy - Rush, D. (2010). *Integrated STEM education through project-based learning*.

Loes, C. N. (2019). Applied learning through collaborative educational experiences. applied learning in higher education: curricular and co-curricular experiences that improve student learning. *New Directions for Higher Education*, *2019*(188), 13–21. https://doi.org/10.1002/he

Lovren, V. O., & Jablanovic, M. M. (2023). Bridging the Gap: The affective dimension of learning outcomes in environmental primary and secondary education. *Sustainability (Switzerland)*, *15*(8), 428-434. https://doi.org/10.3390/su15086370

Madyani, I., Yamtinah, S., Utomo, S. B., Saputro, S., & Mahardiani, L. (2020). Profile of students' creative thinking skills in science learning. *3rd International Conference on Learning Innovation and Quality Education (ICLIQE 2019)*, 957–964.

Mamahit, J. A., Aloysius, D. C., & Suwono, H. (2020a). Efektivitas model project-based learning terintegrasi stem (pjbl-stem) terhadap keterampilan berpikir kreatif siswa kelas x. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *5*(9), 1284–1289.

http://journal.um.ac.id/index.php/jptpp/

Masruroh, Yusuf, D., Maryati, S., Rio Pambudi, M., & Kobi, W. (2024). Peran literasi dalam mendorong kesadaran lingkungan. *Journal Of Khairun Community Services (JKC)*, *4*(1), 2809–1647. https://lmsspada.kemdikbud.go.id,

Maulana. (2020). Penerapan model project based learning berbasis stem pada pembelajaran fisika siapkan kemandirian belajar peserta didik. *Jurnal Teknodik*, *24*(1), 37–48. www.ubaya.ac.id/2014/content/articles_detail/

Maulidiningsih, Kusumaningrum, & Ayu, I. (2023). Model pembelajaran kontekstual pada materi kimia hijau dalam meningkatkan minat belajar siswa. *Jurnal Tadris Kimia*, *2*(1), 11–18. http://www.syekhnurjati.ac.id/Jurnal/index.php/respec/article/view/14260

McBeth, B., Hungerford, H., Marcinkowski, T., Volk, T., & Meyers, R. (2008). *National Environmental Literacy Assessment Project: Year 1, National Baseline Study of Middle Grades Students Final Research Report*.

Muganga, L., & Ssenkusu, P. (2019). Teacher-centered vs. student centered: an examination of student teachers' perceptions about pedagogical practices at uganda's makerere university. *Cultural and Pedagogical Inquiry*, *11*(2), 16–40. http://ejournals.library.ualberta.ca/index.php/cpi/index

Ng, A. W. Y., & Lee, C.-Y. (2019). Assessment of creative thinking of hong kong undergraduate students using the torrance tests of creative thinking. *Fifth International Conference on Higher Education Advances*, 1–8. https://doi.org/10.4995/head19.2019.9051

Nursa'adah, E., Maryani, B., & Ruyani, A. (2021). Students' environmental literacy: environment education assisted e-booklet on biodiversity gegas dam indonesia context. *Thabiea : Journal of Natural Science Teaching*, *4*(2), 159–169. http://journal.iainkudus.ac.id/index.php/Thabiea

OECD. (2024). *PISA 2022 Results Volume III: Creative Minds, Creative Schools*.

Oliveira, J. R. P., Tusset, A. M., Andrade, D. I., Balthazar, J. M., Pagani, R. N., & Lenzi, G. G. (2024). Action plans study: principles of green chemistry, sustainable development, and smart cities. *Sustainability (Switzerland)*, *16*(18), 1–34. https://doi.org/10.3390/su16188041

Parwati, N. P. A., Redhana, I. W., & Suardana, I. N. (2021). Effect of gender on environmental literacy of high school students in bali, indonesia. *Proceedings of the First International Conference on Science, Technology, Engineering and Industrial Revolution (ICSTEIR 2020)*, 332–336.

Paschalidou, K., Salta, K., & Koulougliotis, D. (2022). Exploring the connections between systems thinking and green chemistry in the context of chemistry education: A scoping review. *Sustainable Chemistry and Pharmacy*, *29*.https://doi.org/10.1016/j.scp.2022.100788

Pertiwi, A. M., & Wahyuningrum, D. (2024). The development of green chemistry teaching material based on organic compound synthesis. *EduChemia: Jurnal Kimia Dan Pendidikan*, *9*(2), 132-138. https://doi.org/10.30870/educhemia.v9i1.24452

Pramesti, D., Probosari, R. M., & Indriyanti, N. Y. (2022). Effectiveness of project based learning low carbon stem and discovery learning to improve creative thinking skills. *Journal of Innovation in Educational and Cultural Research*, *3*(3), 444–456. https://doi.org/10.46843/jiecr.v3i3.156

Qomariyah, D. N., & Subekti, H. (2021). Analisis kemampuan berpikir kreatif: studi eksplorasi siswa di SMPN 62 surabaya. *Pensa E-Jurnal : Pendidikan Sains*, *9*(2), 242–246. https://ejournal.unesa.ac.id/index.php/pensa/index

Ratnawati, E., & Praptomo, S. (2023). Penerapan pembelajaran kimia hijau melalui project based learning (PjBL) pada mata pelajaran kimia SMA. *Unesa Journal of Chemical Education*, *12*(2), 141–147.

Rinto, Iswari, R. S., Mindyarto, B. N., & Saptono, S. (2022). Project based learning using etno-stem approach: improving creative thinking skill of pharmacy students at medical vocational high school. *International Conference on Science, Education and Technology (ISET)*, *8*(1), 197–201. https://proceeding.unnes.ac.id/index.php/iset

Ritter, S. M., Gu, X., Crijns, M., & Biekens, P. (2020). Fostering students' creative thinking skills by means of a one-year creativity training program. *PLoS One*, *15*(3), 1-13. https://doi.org/10.1371/journal.pone.0229773

Rokhmah, Z., Maulida, A. N., & Fauziah. (2021). Analisis literasi lingkungan siswa SMP pada sekolah berkurikulum wawasan lingkungan. *Pensa E-Jurnal : Pendidikan Sains*, *9*(2), 176–181. https://ejournal.unesa.ac.id/index.php/pensa/index

Said, U., Zidny, R., Sari, R., & Aisyah, S. (2025). Development of merdeka curriculum teaching modules for pjbl-based green chemistry learning. *EduChemia: Jurnal Kimia dan Pendidikan*, *10*(1), 53–70. https://dx.doi.org/10.30870/educhemia.v10i1.30716

Saimon, M., Lavicza, Z., & Dana-Picard, T. (2023). Enhancing the 4Cs among college students of a communication skills course in Tanzania through a project-based learning model. *Education and Information Technologies*, *28*(6), 6269–6285. https://doi.org/10.1007/s10639-022-11406-9

Santoso, R., Roshayanti, F., & Siswanto, J. (2021). Analisis literasi lingkungan siswa SMP. *Jurnal Penelitian Pendidikan Sains*, *10*(02), 2549–2571. https://journal.unesa.ac.id/index.php/jpps

Somwaeng, A. (2021). Developing early childhood students' creative thinking ability in STEM Education. *Journal of Physics: Conference Series*, *1835*(1). https://doi.org/10.1088/1742-6596/1835/1/012009

Sudarmin, S., Zahro, L., Pujiastuti, S. E., Asyhar, R., Zaenuri, Z., & Rosita, A. (2019). The development of PBL-based worksheets integrated with green chemistry and ethnoscience to improve students' thinking skills. *Jurnal Pendidikan IPA Indonesia*, *8*(4), 492–499. https://doi.org/10.15294/jpii.v8i4.17546

Taskiran, A. (2021). Project-based online learning experiences of pre-service teachers. *Journal of Educational Technology and Online Learning*, *4*(3), 391–405. https://doi.org/10.31681/jetol.977159

Terhemba, W.K., Ayua, G.A., & Gamat, G.B. (2023). Effect of creative-teaching on creative-thinking-originality among different-ability upper-basic science students in gboko township. *AJSTME*, *3*(9), 110–116. https://www.ajstme.com.ng

Tiwari, V.K., Kumar, A., Rajkhowa, S. ·, Tripathi, G., & Singh, A.K. (2022). *Green Chemistry Introduction, Application and Scope* (1st ed.). Springer Singapore.

Torrance, E. P., & Aliotti, N. C. (1969). Sex differences in levels of performance and test-retest reliability on the torrance tests of creative thinking ability. *The Journal of Creative Behavior*, *3*(1), 52–57. https://doi.org/10.1002/j.2162-6057.1969.tb00044.x

Vijaykumar, R., Thamizhiniyan, K., & Naseema, S. (2021). Environmental literacy research: global scientometric mapping of five decades. *Current World Environment*, *16*(3), 963–973. https://doi.org/10.12944/cwe.16.3.26

Widana, I. W., & Septiari, K. L. (2021). Kemampuan berpikir kreatif dan hasil belajar matematika siswa menggunakan model pembelajaran project-based learning berbasis pendekatan STEM. *Jurnal Elemen*, *7*(1), 209–220. https://doi.org/10.29408/jel.v7i1.3031

Widyasmah, M., Abdurrahman, & Herlina, K. (2020). Implementation of stem approach based on project-based learning to improve creative thinking skills of high school students in physics. *Journal of Physics: Conference Series*, *1467*(1). https://doi.org/10.1088/1742-6596/1467/1/012072

Yildirim, M. S., Elkoca, A., Gökçay, G., Yilmaz, D. A., & Yıldız, M. (2025). The relationship between environmental literacy, ecological footprint awareness, and environmental behavior in adults. *BMC Public Health*, *25*(1). https://doi.org/10.1186/s12889-025-21340-3

Yustina, Mahadi, I., Zulfarina, Priawan, O., & Anggraini, D. (2021). The effect of constructivism-based stem on students' creative thinking skills in biotechnology learning. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *4*(4), 9727–9735. https://doi.org/10.33258/birci.v4i4.2995

Zhang, W., Xu, R., Jiang, Y., & Zhang, W. (2021). How environmental knowledge management promotes employee green behavior: An empirical study. *International Journal of Environmental Research and Public Health*, *18*(9), 1–15. https://doi.org/10.3390/ijerph18094738

Zidny, R., & Eilks, I. (2022). Learning about pesticide use adapted from ethnoscience as a contribution to green and sustainable chemistry Education. *Education Sciences*, *12*(4). https://doi.org/10.3390/educsci12040227