International Journal of Educational Development

E-ISSN: 3046-8159
P-ISSN: 3047-1893

Research Article

The Effect of the Use of Project Based Learning (PjBL) Learning Model on the Creativity and Metacognition of Class X Students on Ecoprinting Materials of the Green Chemistry Concept

Noor Hiqmah[1]*, Sri Handayani[2]

[1]Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Yogyakarta, Indonesia; email: noorhiqmah.2022@student.uny.ac.id
[2]Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Yogyakarta, Indonesia; email: handayani@uny.ac.id
***Corresponding Author: e-mail: noorhiqmah.2022@student.uny.ac.id

Abstract: This study aimed to analyze the effect of implementing the Project-Based Learning (PjBL) model through ecoprinting activities on the metacognitive skills and creativity of tenth-grade students in learning green chemistry. A quasi-experimental method with a nonequivalent pretest-posttest control group design was employed. The sample consisted of 72 tenth-grade students from SMA Negeri 4 Tarakan, divided into an experimental group (Class X-2, n = 36), which received PjBL through ecoprinting activities, and a control group (Class X-8, n = 36), which received Inquiry-based learning. Data were collected using pretest and posttest instruments to measure metacognitive skills and observation sheets to assess students' creativity during the learning process. Descriptive analysis indicated that the experimental group achieved higher mean scores in both metacognitive skills and creativity than the control group. The Independent Samples t-test revealed that PjBL through ecoprinting activities significantly improved students' metacognitive skills ($p < 0.001$) and creativity ($p < 0.001$). In addition, MANOVA results showed a significant simultaneous difference between the two groups across both dependent variables (Hotelling's Trace, $p < 0.001$). These findings demonstrate that PjBL integrated with ecoprinting is an effective, contextual, and student-centered instructional approach for enhancing metacognitive skills and creativity in green chemistry learning.

Keywords: Creativity; Ecoprinting; Green chemistry; Metacognitive skills; Project-Based Learning.

Received: January 10, 2026
Revised: March 14, 2026
Received: Juni 15, 2026
Online Available: July 22, 2026
Current ver. : July 22, 2026

1. Introduction

The implementation of the Independent Curriculum provides an opportunity for schools to develop more flexible learning while still integrating the principles of the previous curriculum. One of the subjects that is an important part of the curriculum is chemistry (Ni'mah et al., 2023). Chemistry has characteristics in the form of abstract concepts, calculations, and complex relationships between concepts so that it often causes difficulties for students to understand the material. Chemistry learning should not only emphasize mastery of knowledge products, but also scientific processes and the formation of scientific attitudes in order to be able to produce a deep understanding of concepts, problem-solving skills, and scientific mindsets in daily life (Nisa & Harrista, 2022).

One of the materials that is relevant to the development of science and sustainability issues is green chemistry. This concept focuses on designing chemical products and processes that are able to minimize the use and formation of harmful substances so that their impact on humans and the environment can be reduced. Although the use of chemicals in industry cannot be completely avoided, the application of green chemistry principles can reduce waste and improve resource efficiency (Płotka-Wasylka et al., 2018). Green chemistry material in the Independent Curriculum is also directed to develop critical thinking skills through the analysis of various scientific problems encountered in daily life while increasing students' environmental awareness (Aubrecht et al., 2019).

However, the implementation of green chemistry learning in schools still faces various obstacles. The results of observations at SMA Negeri 4 Tarakan City show that learning is still dominated by simple lecture and discussion methods so that learning activities are more teacher-centered. The teacher also said that green chemistry material is a relatively new material so that there are not many contextual and applicable learning activities available. The analysis of the learning tools showed that the activities provided were still oriented towards low-level cognitive abilities and did not involve much investigation, experimentation, or projects based on environmental problems. As a result, students have not had optimal opportunities to develop creativity and metacognitive skills, such as planning, monitoring, and evaluating their thought processes during learning.

One of the alternatives that is considered to be able to overcome this problem is the application of the Project Based Learning (PjBL) model. Various studies have shown that PjBL contributes positively to the improvement of creative thinking skills because students are directly involved in the completion of projects that demand exploration of ideas and problem-solving (Nastiti et al., 2023). In addition, the application of Integrated Project Based Learning (I-PjBL) has also been proven to be able to improve metacognitive skills, both in terms of knowledge and cognitive regulation, so that students are better able to control their own learning process (Maryani et al., 2020).

In learning green chemistry, project activities that can be applied are ecoprinting. This technique utilizes natural pigments from leaves, flowers, or other plant parts to produce motifs on the fabric so that it is more environmentally friendly than the use of synthetic dyes (Afrahamiryano et al., 2022). The ecoprinting process contains various chemical concepts, such as pigment extraction, the interaction of natural compounds with fabric fibers, the use of relatively safe solvents, and the application of the principles of using renewable materials and reducing chemical waste. Therefore, ecoprinting is not only a creative activity, but can also be used as a contextual learning medium in understanding the principles of green chemistry in real life (Juwono et al., 2024).

The implementation of the ecoprinting project allows students to develop creativity as well as metacognitive skills. During the project process, students must design work steps, choose materials, monitor the implementation of activities, and evaluate the results obtained. These activities are part of metacognitive regulation that helps students control their thinking processes. On the other hand, freedom in determining motives, choosing plant types, and producing different products encourages the emergence of creative ideas and the ability to innovate. Thus, project-based learning through ecoprinting has the potential to increase understanding of the concept of green chemistry while developing 21st century competencies (Dhita et al., 2025).

Although the effectiveness of Project Based Learning in improving high-level thinking skills has been widely reported, research that integrates PjBL with ecoprinting activities on green chemistry materials, especially those that examine its effect on students' metacognitive skills and creativity simultaneously, is still limited. Therefore, this study was conducted to analyze the effect of the application of Project Based Learning through ecoprinting activities on the metacognitive skills and creativity of grade X students of SMA Negeri 4 Tarakan City on green chemistry material. The novelty of the research lies in the integration of the Project Based Learning model with ecoprinting as a contextual learning medium that supports continuous education while developing students' creativity and metacognitive skills.

This study aims to analyze the differences in metacognitive skills and creativity between students who learn using the Project Based Learning (PjBL) model and the Inquiry model on green chemistry material. In addition, this study aims to examine the effect of the application of Project Based Learning (PjBL) on the metacognitive skills and creativity of class X students of SMA Negeri 4 Tarakan City on green chemistry material.

2. Literature Review

Project Based Learning (PjBL) is a learning model that places students at the center of the learning process through project completion related to real problems. In this model, students work independently or in groups to design, implement, and present products as learning outcomes. The characteristics of PjBL include active student involvement from the planning stage to evaluation, responsibility for projects, cooperation with various parties, development of creative thinking skills, and the creation of a learning environment that supports the emergence of various ideas (Yoki Ariyana et al., 2018). According to Warsono et al. (2013), PjBL uses real-life problems as a means to help students understand basic learning concepts and principles. Before the implementation of the project, teachers need to identify the competencies to be developed, determine relevant topics, motivate students, and ensure the availability of learning resources, facilities, and appropriate time allocation.

The implementation of PjBL increases student involvement through various learning activities, such as direct observation, searching for information from various sources, research, and collaboration with teachers and peers. This condition expands learning resources while increasing motivation because students are encouraged to find answers to the problems they face independently (Pradita et al., 2015).

Green Chemistry is an approach in chemistry that focuses on designing chemical products and processes that are safer and able to reduce negative impacts on the environment (Ratnawati et al., 2023). This approach emphasizes pollution prevention through the use of materials, processes, and technologies that can minimize the formation of waste and pollutants from the beginning. In addition, Green Chemistry also encourages the efficiency of the use of energy, water, and other resources so that the use of natural resources becomes more sustainable (Karpudewan et al., 2012). The application of this concept not only aims to reduce ecosystem damage, but also increase public awareness of the impact of chemicals and the importance of preserving the environment (Günter et al., 2017).

As a guideline in the development of sustainable chemical processes, Anastas and Warner (1998) formulated twelve principles of Green Chemistry, namely Prevention, Atomic Economy, Less Hazardous Chemical Syntheses, Designing Safer Chemicals, Safer Solvents and Auxiliaries, Design for Energy Efficiency, Use of Renewable Feedstocks, Reduce Derivatives, Catalysis, Design for Degradation, Real-time Analysis for Pollution Prevention, and Inherently Safer Chemistry for Accident Prevention. These principles emphasize waste prevention, the use of renewable raw materials, energy efficiency, the reduction of the use of hazardous chemicals, the selective use of catalysts, and the design of products that are easily degradable so that they are safer for humans and the environment (Anastas & Warner, 1998).

Ecoprinting is a technique for printing motifs on fabrics by utilizing natural pigments derived from leaves, flowers, and other plant parts. This process is carried out through direct contact between plant materials and fabrics so that pigments transfer and form natural patterns on the surface of the fabric. In chemistry learning, ecoprinting not only produces products that have aesthetic value, but also becomes a medium to study the concept of pigment extraction, chemical interactions between pigments and fabric fibers, and the application of Green Chemistry principles (Afrahamiryano et al., 2022).

The application of ecoprinting also reflects several principles of Green Chemistry, especially Renewable Feedstocks through the use of natural materials as a source of pigment, Safer Solvents and Auxiliaries with the use of water as a solvent, Prevention through the reduction of synthetic dye waste, and Design for Energy Efficiency because the process is relatively simple and requires lower energy than the conventional textile industry (Fatihah et al., 2025).

Metakogance is the ability of individuals to understand, regulate, and control their own thought processes. Cognition includes all mental activities related to receiving, processing, storing, remembering, and utilizing information obtained through the senses (Gama, 2004). In learning, metacognition plays a role at all levels of Bloom's taxonomy, from remembering to creating, so it becomes an important part of developing students' critical thinking skills (Sudirman & Yusnaeni, 2022). According to Moritz et al. (2019), metacognition consists of two main components, namely metacognitive knowledge and metacognitive regulation. Metacognitive knowledge is related to a person's understanding of how their thought process works, while metacognitive regulation is the ability to control and manage the process so that learning goals can be achieved effectively.

Creativity is the ability of individuals to produce new ideas, ideas, and products that are valuable through the process of imaginative thinking and the use of previous experiences in solving various problems (Rajagukguk, 2023). Creativity is also understood as the ability to produce original compositions, products, or ideas, both in the fields of art, science, and the development of certain methods and procedures (Siregar et al., 2022).

In 21st century learning, creativity is seen as a competency that develops through interaction between individuals, the environment, and the learning culture. Mishra and Henriksen (2018) state that creativity is a multidimensional construct that does not only depend on individual abilities, but is also influenced by the learning context. Creativity is also understood as the process of combining knowledge and experience that has been possessed into new and meaningful ideas, so that innovation is not always something completely new, but the result of the development of existing ideas (Mishra & Henriksen, 2018).

Chemistry learning is an important part of science education that plays a role in improving science literacy through an understanding of the structure, properties, changes, and interactions of materials. The learning process focuses not only on the mastery of concepts, but also on the ability of students to apply chemical knowledge to explain various phenomena in daily life. Therefore, learning needs to be designed hollistically, contextually, and meaningfully in order to be able to connect scientific concepts with their application in real life (Müller et al., 2024).

Effective chemistry learning also requires innovative strategies that utilize technology as well as adaptive learning approaches. The integration of technology and context-based learning experiences can help address the abstract nature of chemical materials, increase motivation to learn, while developing 21st-century skills. Through this approach, students not only understand chemical concepts, but also have the ability to think critically, creatively, and be able to better face global challenges (Yoshikai et al., 2024).

3. Research Method

This study uses a quasi experiment method with the aim of analyzing the effect of the application of the Project Based Learning (PjBL) model on students' metacognitive skills and creativity in green chemistry materials. The design applied is a nonequivalent pretest-posttest control group design, which is a design that involves an experimental group and a control group which are given a pretest before treatment and posttest after the learning process is completed, respectively.

The use of quasi experiments was chosen because the research conditions did not allow full randomization of subjects. The class division has been established by the school so that the researcher utilizes existing classes as experimental groups and control groups. Before treatment, both groups were given a pretest to measure the students' initial metacognitive skills and creativity. Furthermore, the experimental group obtained learning using the Project Based Learning (PjBL) model through an ecoprinting project on green chemical materials, while the control group followed the learning using the Inquiry model which is usually applied by teachers. After the entire learning series was completed, both groups were given a posttest to determine changes in students' metacognitive skills and creativity as a result of the treatment given.

The research was carried out at SMA Negeri 4 Tarakan City in the even semester of the 2024/2025 Academic Year. The school was chosen because it has implemented the Independent Curriculum and class X students have studied green chemistry material, so that it is in accordance with research needs. The research population includes all students of class X of SMA Negeri 4 Tarakan City for the 2024/2025 school year which consists of eight classes. The sample was determined using the cluster random sampling technique, because the unit selected was in the form of a class, not individual students (Sugiyono, 2022). Through the drawing process for all classes, classes X-2 and X-8 were obtained as research samples. The next draw was carried out to determine the function of each class, so that class X-2 became an experimental group that obtained learning using Project Based Learning (PjBL) through an ecoprinting project, while class X-8 became a control group that obtained learning using the Inquiry model. Each class consists of 36 students and is taught by the same chemistry teacher with the same material, curriculum, and time allocation. The similarity of learning conditions aims to minimize the influence of external factors so that the difference in research results more reflects the influence of the treatment given, namely the application of the Project Based model

Research data collection is carried out through three main stages, namely the preparation, implementation, and data analysis stages. In the preparation stage, the researcher conducted initial observations in class X of SMA Negeri 4 Tarakan City to obtain information about the learning process that took place, as well as identify needs and potentials that can be used as the basis for the application of the Project Based Learning (PjBL) model and inquiry. Metacognitive skills instruments are used to measure students' ability to plan, monitor, and evaluate thinking processes during learning.

Data analysis begins with a statistical prerequisite test. Normality tests were performed using the Kolmogorov-Smirnov to find out if the data came from a normally distributed population. The data is stated to meet the assumption of normality if the significance value is greater than 0.05. Furthermore, a homogeneity test was carried out using the Levene's Test with the help of IBM SPSS Statistics 25 to determine the similarity of variance between groups. The variance is expressed homogeneously when the significance value exceeds 0.05.

4. Results and Discussion

Research Results

Empirical validity was carried out on grade XI students of SMAN 4 Tarakan who had studied green chemistry material. Analysis using SPSS showed that all items of metacognitive skills questions had a greater r-count value than the r-table (0.339), so that all items were declared valid and suitable for use as research instruments.

Reliability testing was performed using Cronbach Alpha statistics. Based on the criteria, the instrument is declared reliable if it has a Cronbach Alpha value above 0.60. The results of the analysis showed that the metacognitive skills instrument obtained a Cronbach Alpha value of 0.661. This value shows that the instrument has good internal consistency, so that it is able to produce stable, accurate, and reliable data in measuring students' metacognitive abilities.

The results of the descriptive analysis showed that the initial ability of students in the experimental class and the control class was relatively the same. The average pretest score of the experimental class was 71.54, while the control class was 71.41. After the learning process, the average posttest score increased in both groups, but the increase in the experimental class was higher, reaching 91.00 compared to the control class of 81.08. These findings indicate that the application of Project Based Learning (PjBL) provides better metacognitive learning outcomes than Inquiry learning.

Students' creativity was measured using observation sheets during the learning process. The results of the analysis showed that the average creativity of students in the experimental class reached 73.44, while the control class obtained an average of 59.67. These differences show that descriptively the application of Project Based Learning (PjBL) makes a positive contribution to the development of student creativity in green chemistry learning.

Before testing the hypothesis using MANOVA, a prerequisite test was carried out in the form of normality and homogeneity tests. The normality test using Shapiro–Wilk at a significance level of 0.05 showed that most of the variables were normally distributed. Only the experimental class pretest data and the experimental class N-Gain did not meet the normality assumption, while the other variables had normal distributions.

Furthermore, the homogeneity test using Levene's Test showed that all variables had a significance value greater than 0.05. These results show that the variance between the experimental class and the control class is homogeneous, so the data meet one of the important assumptions to continue the hypothesis analysis using MANOVA.

The univariate outlier test was conducted to identify data that had extreme values in each research variable, namely metacognitive, creativity, and N-Gain. The examination was carried out using a boxplot as recommended by Hair et al. (2019). The results of the analysis showed that all variables did not have outliers, so no significantly deviating data was found. Thus, all data is declared eligible and can be used in the next stage of analysis.

The linearity assumption was examined through a scatter plot matrix between dependent variables before the implementation of the MANOVA analysis. Based on the data distribution pattern, the relationships between variables show a linear tendency so that the assumption of linearity is fulfilled. These conditions indicate that the data has met one of the important prerequisites in multivariate analysis.

The homogeneity of the covariance matrix was tested using the Box's M Test as one of the prerequisites for MANOVA (Tabachnick & Fidell, 2019). The test results showed a Box's M value of 0.311 with a significance of 0.960. Since the significance value is greater than 0.05, the covariance matrix between the groups is declared homogeneous. Thus, the homogeneity assumption has been fulfilled so that the MANOVA analysis can be continued.

The initial ability balance between the experimental group and the control group was analyzed using the Mann–Whitney U Test because there were indications that the data did not fully meet the assumption of normality (Field, 2018). The results of the analysis obtained a significance value of 0.858 (>0.05), which showed that there was no difference in initial ability between the two groups. Therefore, both groups were considered to have equal initial conditions before being given treatment.

The first hypothesis was tested using MANOVA after all analysis prerequisites were met. The test aims to find out whether there is a difference in metacognitive ability and creativity in learning simultaneously between students who participate in learning using the Project Based Learning (PjBL) model and students who learn with the inquiry model on green chemistry materials. Hotelling's Trace results showed a significance value of less than 0.001, so the null hypothesis was rejected. These findings show significant differences in the two dependent variables together between the experimental group and the control group.

The second hypothesis aims to test the difference in metacognitive abilities between students who learn using Project Based Learning (PjBL) through the ecoprinting project and students who participate in inquiry learning. The analysis was carried out using Independent Samples t-test because the homogeneity assumption has been met (Field, 2018). The test results resulted in a significance value of less than 0.001 so there was a significant difference between the two groups. In addition, Cohen's d value of 1.540 shows that the application of Project Based Learning (PjBL) through ecoprinting has a large effect on metacognitive ability.

The third hypothesis analyzes the difference in student creativity between the group that participated in Project Based Learning (PjBL) through ecoprinting and the group that used the inquiry model. The results of the Independent Samples t-test showed a significance value of less than 0.001 so that there was a significant difference in creativity between the two groups. The experimental group's average creativity score was higher than that of the control group, while Cohen's d score of 2.181 indicated that the treatment had a very large effect on improving students' creativity.

The effectiveness of learning was analyzed using the Mann–Whitney U Test on N-Gain scores. The test results showed a significance value of less than 0.001, so there was a significant difference in learning outcomes between the two groups. The experimental group obtained a higher N-Gain value than the control group. This shows that learning using Project Based Learning (PjBL) through the ecoprinting project is more effective in improving learning outcomes on green chemistry materials than the inquiry learning model.

Discussion

Differences in Metacognitive Skills and Creativity of Students Using Project Based Learning (PjBL) and Inquiry Models

Students' metacognitive abilities were measured through a pretest and posttest, each consisting of 10 description questions. The research instrument has gone through theoretical validation by two lecturers of Chemistry Education at Yogyakarta State University (UNY) as well as empirical validation on 36 grade XI students of SMA Negeri 4 Tarakan. The test results showed that all question items were declared valid so that they were suitable for use as research instruments.

The difference in metacognitive ability and creativity between the experimental class that applied Project Based Learning (PjBL) and the control class that used the inquiry model was analyzed using the MANOVA (Hotelling's Trace) test. The results of the analysis showed a significance value of less than 0.05 ($p < 0.001$), so there was a significant difference in students' metacognitive abilities and creativity simultaneously. These results show that the implementation of PjBL has a better impact than the inquiry model in developing these two aspects.

This finding is supported by research by Anggarani and Hidayat (2019) who stated that Project Based Learning (PjBL) is effective in improving students' metacognitive skills. Research by Siregar et al. (2022) also reported that the application of PjBL-based teaching materials was able to encourage the development of creativity in chemistry learning. In addition, Ratnawati et al. (2023) found that the implementation of PjBL in green chemistry learning significantly improved student learning outcomes. Based on these findings, Project Based Learning (PjBL) has been proven to be able to develop metacognitive skills, creativity, and learning outcomes in an integrated manner so that it is feasible to apply as a student-centered learning model and relevant to the context of chemistry learning (Ratnawati et al., 2023).

The Influence of Project Based Learning (PjBL) Learning Model on Students' Metacognitive Abilities

The results showed that the students' metacognitive abilities in the experimental class were higher than those in the control class. The average posttest score of classes using Project Based Learning (PjBL) reached 91.00, while classes with the inquiry model obtained an average of 81.08. These differences show that the application of PjBL provides a better understanding of ecoprinting materials in the concept of green chemistry.

This advantage occurs because Project Based Learning (PjBL) places students as the center of learning through activities of seeking information, developing strategies, solving problems, and evaluating project results independently. In the ecoprinting project, students design the stages of work, select suitable materials, identify obstacles, and determine solutions during the process. The activity trains metacognitive skills, especially in the aspects of planning, monitoring, and evaluation, so that students are better able to control the learning process.

An improvement in metacognitive skills was also seen during the implementation of the ecoprinting project. In the planning stage, students determine the type of leaves or flowers, choose mordant materials, and arrange work procedures. During the process of mordanting, preparing motifs, and printing, students monitor the progress of the project while adjusting strategies if they encounter obstacles. After the project is completed, students reflect on the prints to evaluate the successes and shortcomings of the process that has been carried out. The series of activities reflects the application of the main components of metacognition which include planning, monitoring, and evaluation (Veenman et al., 2017).

The results of this study are in line with Ramadhan et al. (2017) who stated that Project Based Learning (PjBL) is effective in improving metacognitive skills through creative thinking activities. These findings are strengthened by Anggarani and Hidayat (2019) who show that PjBL is able to develop metacognitive skills significantly. In addition, Hidayah et al. (2025) explained that project-based learning integrated with green chemistry helps students manage the learning process, reflect, and evaluate work results independently. Sumarni et al. (2016) also emphasized that PjBL provides an authentic learning experience that encourages the development of high-level thinking skills. Thus, the implementation of the ecoprinting project not only strengthens the understanding of the concept of green chemistry, but is also effective in improving students' metacognitive abilities (Veenman et al., 2017).

3. The Influence of Project Based Learning Models on Creativity

The results of the observation showed that the average creativity of students in the experimental class (73.44) was higher than that of the control class (59.67). These differences indicate that the implementation of Project Based Learning (PjBL) has a positive influence on increasing student creativity in the learning process. This success is related to the student-centered characteristics of PjBL so that they have the opportunity to explore ideas, design projects, solve problems, and produce products based on their own thinking. This process encourages the development of creative thinking skills while producing more innovative solutions and ideas.

The application of ecoprinting projects based on green chemistry concepts provides a contextual learning experience as students not only understand concepts theoretically, but also apply them in real-life activities. During the learning process, students have the flexibility to determine the design, choose natural materials, adjust the color composition, and modify the manufacturing technique according to the creativity of each group. The opportunity to explore is an important factor that supports the development of student creativity. Project-based learning also allows students to integrate knowledge with creativity through problem-solving and product creation. The results of this study are in line with the findings of Fitriyah and Ramadani (2021) which show that the application of STEAM based on PjBL is able to improve students' creative thinking skills.

The creativity of students in the experimental class is further developed through ecoprinting projects that provide ample space to produce different works. Students are free to choose the type of leaves and flowers, combine natural materials, arrange mold patterns, and develop product designs according to the characteristics of the group. These activities encourage the emergence of various ideas (fluency), the use of various strategies (flexibility), the creation of unique designs (originality), and the ability to improve product details (elaboration). These results are consistent with the research of Irdalisa et al. (2024) who stated that the integration of ecoprint techniques in project-based learning is able to increase creativity through the development of ideas and the creation of real products. The research of Agustin and Mitarlis (2025) also showed that project-based learning on green chemistry materials significantly improves students' creative thinking skills, while Dewi et al. (2024) found that ecoprinting activities encourage the creative use of natural resources so as to produce innovative works with aesthetic value.

The presentation stage of project results also supports increased creativity because students not only display products, but also explain the thinking process, reasons for choosing designs, and strategies for overcoming obstacles during project work. These activities provide an opportunity to reflect as well as obtain feedback from teachers and peers that can enrich the creative thinking process (Irdalisa et al., 2024).

Although the results of the study show that PjBL through the ecoprinting project has an effect on students' creativity and metacognitive skills, there are other factors that have the potential to affect the results of the study. One of them is the novelty effect, which is the increase in students' enthusiasm because they get different learning experiences through practical activities, the use of natural materials, and the creation of real products. In addition, the role of teachers as facilitators in providing direction, feedback, and mentoring during projects also contributes to learning success (Kokotsaki et al., 2016). Group work factors, learning motivation, early ability, interest in practicum, and previous learning experiences alsoaffect the development of students' creativity and metacognitive skills. Therefore, the results of the study need to be understood by considering the possible influence of these various factors.

4. Conclusion

Based on the results of the research, it can be concluded that the application of the Project Based Learning (PjBL) model through the ecoprinting project on green chemical materials provides better learning outcomes than the Inquiry model. Students who learned using Project Based Learning (PjBL) showed higher metacognitive skills, and the difference was shown to be significant based on the results of the Independent Samples t-test ($p < 0.001$). In addition, this learning model was also able to significantly increase students' creativity compared to the group that obtained learning with the Inquiry model ($p < 0.001$).

At the same time, the improvement of students' metacognitive skills and creativity in classes that applied Project Based Learning (PjBL) through ecoprinting projects was also higher than in classes that used the Inquiry model. The results of MANOVA's analysis through Hotelling's Trace value ($p < 0.001$) showed a significant difference between the two groups. Thus, the implementation of Project Based Learning (PjBL) based on the ecoprinting project has proven to be effective in developing metacognitive skills as well as students' creativity in green chemistry learning.

References

Afrahamiryano, A., Roza, H., Dewi, R. K., Wati, D. D. E., Hanafi, I., & Amri, C. (2022). Edukasi dan pemanfaatan bahan alam untuk pembuatan *ecoprint*. *Community Development Journal: Jurnal Pengabdian Masyarakat, 3*(2), 1209–1213. https://doi.org/10.31004/cdj.v3i2.5714

Anastas, P. T., & Warner, J. C. (1998). *Green chemistry: Theory and practice*. Oxford University Press.

Anggarani, F., & Hidayat, B. (2019). Pengaruh penggunaan model *Project-Based Learning* (PjBL) terhadap keterampilan metakognitif dalam pembelajaran sejarah siswa kelas X Farmasi. *Jurnal Swarnadwipa, 3*, 29–36.

Aubrecht, K. B., Bourgeois, M., Brush, E. J., Mackellar, J., & Wissinger, J. E. (2019). Integrating green chemistry in the curriculum: Building student skills in systems thinking, safety, and sustainability. *Journal of Chemical Education, 96*(12), 2872–2880. https://doi.org/10.1021/acs.jchemed.9b00354

Dhita Ayu Puspitasari, D., Dhea Rizky Amelia, F., Fovy Meisy Wulandari, & A. A. M. (2025). Penerapan *eco print* sebagai metode pembelajaran kreatif. *48–52*.

Fatihah, W., Anggraeni Kasih Astuti, A., Kahal kel Suralaya kec Pulomerak kota Cilegon, K., Raya Anyer, J. K., & Serang, K. (2025). *Ecoprint*: Alternatif pendidikan karakter pada pokok bahasan kimia hijau dan pembangunan yang berkelanjutan. *Jurnal Pendidikan IPA, 15*(1), 1–8. https://doi.org/10.24929/lensa.v15i1.567

Fitriyah, A., & Ramadani, S. D. (2021). Pengaruh pembelajaran STEAM berbasis PjBL (*Project-Based Learning*) terhadap keterampilan. *Journal of Chemistry and Education (JCAE), 10*(1), 209–226.

Gama, C. A. (2004). *Integrating metacognition instruction in interactive learning environments*. University of Sussex.

George, D., & Mallery, P. (2003). *SPSS for Windows step by step: A simple guide and reference 11.0 update* (4th ed.). Allyn & Bacon.

Günter, T., Akkuzu, N., & Alpat, Ş. (2017). Understanding "green chemistry" and "sustainability": An example of problem-based learning (PBL). *Research in Science and Technological Education, 35*(4), 500–520. https://doi.org/10.1080/02635143.2017.1353964

Juwono, H., Hesti, A., Tachtiar, A., Bellyanda, F. P., Rahma, I., Chairunnisa, K., Hardianto, R., & Fatimah, R. R. (2024). Pemberdayaan ekonomi kreatif melalui pelatihan *ecoprint* pada *tote bag* Dusun Todangsan, Kelurahan Tonggalan, Klaten. *2*(2), 379–384.

Karpudewan, M., Ismail, Z., & Roth, W. M. (2012). Ensuring sustainability of tomorrow through green chemistry integrated with sustainable development concepts (SDCs). *Chemistry Education Research and Practice, 13*(2), 120–127. https://doi.org/10.1039/c1rp90066h

Maryani, I., Putri, D. R., Urbayatun, S., Suyatno, & Bhakti, C. (2020). Metacognition and integrated-project based learning (I-PjBL) in elementary schools. *Universal Journal of Educational Research, 8*(3), 1046–1054.

Mishra, P., & Henriksen, D. (2018). *Creativity, technology & education: Exploring their convergence*. https://doi.org/10.1007/978-3-319-70275-9

Moritz, S., Klein, J. P., Lysaker, P. H., & Mehl, S. (2019). Metacognitive and cognitive-behavioral interventions for psychosis: New developments. *Dialogues in Clinical Neuroscience, 21*(3), 309–317. https://doi.org/10.31887/DCNS.2019.21.3/smoritz

Müller, C. H., Reiher, M., & Kapur, M. (2024). Embodied preparation for learning basic quantum chemistry: A mixed-method study. *Journal of Computer Assisted Learning, 40*(2), 715–730. https://doi.org/10.1111/jcal.12909

Nastiti, L. R., Sunarno, W., Saputro, S., Sukarmin, S., Chusni, M. M., & Qamariyah, Z. (2023). Project-based learning's effectiveness in teaching science creative thinking capabilities: Meta-analysis. *AIP Conference Proceedings: The 3rd International Conference on Science Education and Technology (ICOSETH 2021)*, 100007. https://doi.org/10.1063/5.0159781

Ni'mah, F., Syarpin, Fatah, A. H., Alda, & Pasha, M. N. (2023). Pembelajaran kimia berbasis projek melalui pemanfaatan sumber daya lokal sebagai upaya implementasi Kurikulum Merdeka bagi guru MGMP Kimia Kota Palangka Raya. *Bubungan Tinggi: Jurnal Pengabdian Masyarakat, 5*(2), 736–743.

Nisa, A. R. K., & Harrista, S. (2022). Efektivitas pembelajaran PjBL (*Project-Based Learning*) terhadap pemahaman materi kimia pada pembelajaran jarak jauh. *Jurnal Pendidikan, Agama dan Budaya, 6*(2), 141–147.

Płotka-Wasylka, J., Kurowska-Susdorf, A., Sajid, M., de la Guardia, M., Namieśnik, J., & Tobiszewski, M. (2018). Green chemistry in higher education: State of the art, challenges, and future trends. *ChemSusChem, 11*(17), 2845–2858. https://doi.org/10.1002/cssc.201801109

Pradita, Y., Mulyani, B., & Redjeki, T. (2015). Penerapan model pembelajaran *Project-Based Learning* untuk meningkatkan prestasi belajar dan kreativitas siswa pada materi pokok sistem koloid kelas XI IPA semester genap Madrasah Aliyah Negeri Klaten tahun pelajaran 2013/2014. *Jurnal Pendidikan Kimia (JPK), 4*(1), 89–96.

Rajagukguk, S. (2023). Penerapan *Project-Based Learning* untuk meningkatkan kreativitas siswa SD. *Elementary: Jurnal Inovasi Pendidikan Dasar, 3*(1), 1–12. https://doi.org/10.51878/elementary.v3i1.1945

Ratnawati, E., Praptomo, S., Negeri, S., & Tulungagung, K. (2023). Penerapan pembelajaran kimia hijau melalui *Project-Based Learning* (PjBL) pada mata pelajaran kimia SMA. *UNESA Journal of Chemical Education, 12*(2), 141–147.

Siregar, A. D., Ravico, & Harahap, L. K. (2022). Upaya meningkatkan kreativitas mahasiswa menggunakan bahan ajar kimia berbasis *Project-Based Learning* (PjBL). *CHEDS: Journal of Chemistry, Education, and Science, 6*(1), 1–6.

Sudirman, & Yusnaeni. (2022). Korelasi metakognitif dengan retensi belajar siswa SMA Negeri di Kabupaten Rote Ndao Nusa Tenggara Timur. *JRPK: Jurnal Riset Pendidikan Kimia, 12*(1), 1–9. https://doi.org/10.21009/jrpk.121.01

Yoki Ariyana, Pudjiastuti, A., Bestary, R., & Zamron. (2018). *Buku pegangan pembelajaran berorientasi pada keterampilan berpikir tingkat tinggi* (Draf). Direktorat Jenderal Guru dan Tenaga Kependidikan.

Yoshikai, Y., Mizuno, T., Nemoto, S., & Kusuhara, H. (2024). Difficulty in chirality recognition for transformer architectures learning chemical structures from string representations. *Nature Communications, 15*(1), 1–12. https://doi.org/10.1038/s41467-024-45102-8