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Scientific creativity of prospective teachers through eco-friendly project-based blended learning

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ABSTRACT

Scientific creativity is essential for addressing the challenges and problems of the 21st century. Beyond knowledge, creativity is widely regarded as a key component of students' abilities. However, developing this creative skill is challenging because it differs from other educational objectives. This research aims to examine how the application of Project-Based Blended Learning (PBBL) can enhance the scientific creativity of prospective teachers and analyze the impact of this method on promoting a more sustainable and eco-friendly learning process. The study is descriptive quantitative, utilizing instruments such as students' response questionnaires and scientific creativity tests involving 110 prospective science teachers from the Sciences Education Study Program at Universitas Pendidikan Ganesha. Data analysis was conducted using N-Gain, Jonckheere-Terpstra (J-T), and Kruskal-Wallis tests. Initial responses indicated that students understood education for sustainable development and were prepared to develop eco-friendly 3D teaching aids. The scientific creativity tests yielded an average N-Gain value of 0.76. Moreover, the application of eco-friendly practices within PBBL significantly increased the scientific creativity of prospective teachers. Factors such as active student involvement, environmental awareness, and appropriate technological support further strengthened the positive impact of eco-friendly practices on scientific creativity. These findings suggest that PBBL is effective not only in enhancing scientific creativity but also in guiding future educators toward adopting more sustainable pedagogical practices.

Contribution/Originality: This research provides a new perspective by combining three main elements, comprising Project-Based Learning (PjBL), blended learning, and environmental awareness, which have not been widely explored simultaneously in the context of teachers' education. The analysis results can serve as a reference for the development of curriculum and learning strategies that are more relevant to global challenges, such as environmental issues, while preparing creative and environmentally conscious prospective teachers.

1. INTRODUCTION

Along with the development of the times, teachers are required to increase their creativity in facing the challenges of 21st-century learning by considering various social, economic, health, and environmental issues. This creative skill can assist in packaging learning that contains sustainable values into education for sustainable development (ESD) (Erlina, Warpala, & Juniartina, 2022). Science learning, which serves as a basis for environmental learning, plays an important role in protecting the environment (Campbell & Speldewinde, 2022; Güler, Eyüpoğlu, Taş, & Büyükşahin, 2023). However, environmentally-based learning or eco-friendly learning has become a trend in science learning for the past few decades (Brundiers et al., 2021; Hernández-Barco, Sánchez-Martín, Corbacho-Cuello, & Cañada-Cañada, 2021; Muafiah, Afifah, Nurohman, Huda, & Siswadi, 2021; Uralovich & Toshmamatovich, 2023). Various demands for learning development, specifically science learning, show the need for prospective teachers not only to master the scope of science fields but also to have skills that support or align with 21st-century competencies (González-Pérez & Ramírez-Montoya, 2022; Haug & Mork, 2021). Based on multiculturalism and information technology, pedagogical competence is urgently needed in facing the expanding process of globalization (Ridei, 2021). This competence, which is balanced with creativity and scientific reasoning, is expected to help teachers solve students' learning problems comprehensively. Meanwhile, research shows that prospective teachers often have difficulty in identifying, explaining, and solving problems systematically (Csanadi, Kollar, & Fischer, 2021).

Universities are currently trying to improve students' ability to solve real-world problems in a professional context. Learning, which previously focused on academic development and research, is slowly shifting to training in various professional skills, including problem solving (Guo, Saab, Post, & Admiraal, 2020). Project-Based Learning (PjBL) is one of the learning methods widely used in universities. This method presents authentic problems that students must solve, requiring them to apply various interdisciplinary concepts and supporting skills (MacLeod & Van der Veen, 2020). Scientific creativity becomes one of the supporting skills for solving the challenges faced in learning. Research shows that students with high creativity demonstrate strong enthusiasm by expressing various ideas and personal views during the project discussion process, while those with low creativity appear more passive (Wu & Wu, 2020).

The demands of 21st-century skills require various educational institutions to continue innovating in new forms of learning that can optimize abilities and facilitate the diversity of students' needs (Faraniza, 2021). Currently, information technology has become one of the mandatory components that are part of the learning process in several educational institutions. The implementation of learning activities integrated with technology, such as blended learning, has become one of the popular learning implementation options lately, with various benefits ranging from time flexibility to eliminating distance barriers (Kumar et al., 2021). Blended learning supports the process of developing a variety of skills and provides modalities and opportunities to enhance students' self-regulation and learning experiences by increasing access to learning content and training. It also optimizes learning by offering the freedom to explore information at various levels of comprehension and absorption (Suartama, Setyosari, & Ulfa, 2019).

Creativity is an original action containing novelty that produces products, whether physical objects or mental and emotional ideas (Walia, 2019). It is often associated with the ability to solve problems through the interaction of experience, knowledge, and imagination (Calavia, Blanco, & Casas, 2021; Walia, 2019). Creativity is often associated with art, although it is required by other fields such as science. Similar to artists, scientists need creativity in conducting long investigations related to scientific innovation to produce discoveries (Lehmann & Gaskins, 2019). Therefore, scientific creativity can be defined as any thought or behavior in science that is new and useful (De Vries & Lubart, 2019). It is important in facing the challenges and problems of the 21st century. Apart from knowledge, creativity is currently widely considered one of the components of students' abilities. In reality, this creative skill is difficult to achieve because it is often different from other educational goals (Calavia et al., 2021). Creativity is not only possessed by some students but can be developed in all of them. However, teachers are not professionally ready to teach creative thinking, as a result of the lack of support from the education system (De Vries & Lubart, 2019). Scientific creativity of prospective teachers serves as the ability to develop new innovative ideas in the context of learning and teaching based on scientific and technological methods. This creative skill includes critical thinking, problem solving, and the ability to connect concepts to produce new solutions or more efficient ways in the learning process (Runco & Acar, 2012; Yustina, Syafii, & Vebrianto, 2020). For prospective teachers, scientific creativity is important because they are not only expected to master the teaching material but also to be able to create an interesting, inspiring, and motivating learning environment for students. This creativity further includes the ability to adapt new technology in teaching and to deliver complex material in a way that is easy to understand (Li, Kim, & Palkar, 2022). The integration of eco-friendly practices in PjBL allows prospective teachers to develop their creativity in designing a curriculum that is more relevant to global challenges, such as climate change, and in forming the character of students who care about environmental sustainability. In this case, scientific creativity of prospective teachers is not only observed from teaching abilities but also in how they can bring positive changes in environmental perspectives for future generations. Other research has suggested the importance of scientific creativity as a skill that future prospective teachers must have (Cremin & Barnes, 2017; Wahyudi & Winanto, 2018; Yustina et al., 2020). Scientific creativity, which serves as a support for problem-solving abilities, is greatly needed in the increasingly complex world of education. Coupled with the need to support Sustainable Development Goals (SDGs), the field of education is required to instill sustainable values in learning, particularly eco-friendly learning.

Eco-friendly in the context of learning refers to an approach that focuses on the principles of sustainability and environmental friendliness. In the Project-Based Blended Learning (PBBL) method, this concept is applied by integrating environmental issues into learning projects, both online and offline, to increase students' awareness of the importance of preserving nature and utilizing resources efficiently (Anderson & Dill, 2000). Some examples of the application of eco-friendly practices in PBBL are projects involving the analysis of waste management in the environment around the school or community. The use of recycled materials in creative projects involves the creation of learning aids (Garrison & Kanuka, 2004). Learning combines materials on the principles of sustainability, the use of renewable energy, and reducing carbon footprints in daily life (UNESCO, 2019). With this method, students not only learn from theory but also experience directly how eco-friendly practices can be applied in daily life, thereby increasing their scientific maturity and sensitivity to environmental issues. The problems of this research are (1) How can the application of eco-friendly concepts in PBBL encourage increased scientific creativity of prospective teachers? (2) What are the factors that influence the effectiveness of using eco-friendly concepts in PBBL learning model in the context of prospective teachers' education? (3) How can prospective teachers apply eco-friendly-based learning outcomes in their future teaching practices?

2. METHOD

2.1. Research Design

This research employed a quasi-experimental method with a pretest-posttest design across three replication groups. A total of 110 prospective science teachers, enrolled in the Science Education Media and Teaching Aids Production course, participated as subjects. All participants were undergraduate students officially registered in the Science Education Study Program at Universitas Pendidikan Ganesha during the 2023/2024 academic year. Each replication group met the requirements for statistical homogeneity. The research aimed to analyze the effectiveness of PBBL on the scientific creativity of prospective science teachers before and after their participation in the learning process. The research design is presented in Table 1.

Table 1. Pre-post design.

Replication 1	**O_1**	**X_1**	**O_2**
Replication 2	O_1	X_1	O_2
Replication 3	O_1	X_1	O_2

Note: Description:
O_1 = Initial observation (Before treatment).
X_1 = Treatment of project based blended learning.
O_2 = Final observation (After treatment).

2.2. Procedure

This research was conducted through the following PBBL stages.

1. Project Planning (Planning Stage)
    1) Identify Eco-Friendly Theme: The early stage involved the determination of a project theme related to sustainability principles and environmental issues, such as waste management, climate change, renewable energy use, or biodiversity conservation.
    2) Determine Learning Objectives: Determine clear learning objectives, such as raising awareness of the importance of sustainability, developing project-based skills, and building critical and creative thinking skills in addressing environmental issues.
    3) Technology Integration and Online Learning: Determine the learning platform that will be used to integrate online elements into PBBL. This platform can include digital-based learning tools, particularly project management applications or online learning resources that support environmentally-based teaching.
2. Project Design and Development Phase
    1) Building Eco-Friendly Projects: The designed project must involve components that support sustainability, such as the use of recycled materials, eco-friendly product design, or environmental system analysis. The project can be in the form of creating a waste management model, building a vertical garden, or researching renewable energy.
    2) Forming a working team: Prospective teachers or students are divided into groups to work together, developing eco-friendly project-based solutions. This group-based project aims to improve collaboration and creativity skills.
    3) Using blended learning technology: combining online and offline learning. The online part includes research, online presentations, and discussions on environmental issues. The offline part involves hands-on experiments, field trips, or implementing physical projects that support sustainability.
3. Project Implementation (Implementation Stage)
    1) Implementation of online learning: Use online media to convey basic theories about sustainability, provide information about eco-friendly technologies, and offer guidance on effective ways to manage the project.
    2) Offline Practical Project: Perform the hands-on project outside the classroom, such as environmental experiments or building models based on eco-friendly materials. For example, students can work by collecting plastic waste to be recycled into useful items or conducting field research on renewable energy management.
    3) Wise Use of Natural Resources: During the implementation of the project, prospective teachers are expected to be able to teach students to use resources wisely, reduce waste, and consider the environmental impact of every decision they make.
4. Evaluation and Reflection Stage
    1) Project Evaluation: At this stage, evaluate the outcome of the project by assessing the skills students have acquired, such as creativity, problem-solving, and teamwork. Focus on eco-friendly aspects implemented in the project.
    2) Use of assessment rubric: Use a rubric that assesses how students apply sustainability principles, including how they reduce environmental impact and effectively integrate technology in completing the project.
    3) Reflection: Teacher candidates and students are asked to reflect on the learning process that has been carried out. Do they feel more concerned about the environment? How can these groups apply such learning in their daily lives and future teaching?

5. Presentation and Dissemination of Results (Presentation & Dissemination Stage)
    1) Project Result Presentation: After the project is completed, prospective teachers or students present their results, whether online (e.g., through videos, online reports) or offline (e.g., through exhibitions or live discussions).
    2) Spreading eco-friendly knowledge: The project result presentation aims to spread information about sustainability and invite others to participate in protecting the environment. Students or prospective teachers are expected to inspire others to follow in their footsteps in applying eco-friendly principles.
6. Integration of Results in Daily Life and Teaching (Integration Phase)
    1) Utilization of Learning in Teaching Practice: After the project is completed, prospective teachers can plan to apply the learning results in their future curriculum. Teachers can integrate eco-friendly projects into learning activities to teach students about sustainability.
    2) Application of eco-friendly principles in teaching: prospective teachers can develop teaching methods that involve sustainability and eco-friendly principles, such as using teaching materials, reducing paper use, or educating students about the importance of reducing plastic waste.

This procedure aims to create a learning experience that not only enhances the scientific creativity of prospective teachers but also contributes to efforts to preserve the environment in education. The characteristics of eco-friendliness in PBBL are as follows: (a) Efficient Resource Utilization: minimizing the use of energy and other natural resources during the learning process and the project; (b) Waste Reduction: using recycled materials and reducing waste of physical learning materials; (c) Eco-Friendly Technology: using digital learning tools that are more efficient than printed materials or resources consuming more energy; and (d) Environmental Awareness: building students' awareness of environmental issues through the implementation of a project that focuses on sustainability.

2.3. Instruments

The instruments used in this research include the Scientific Creativity Test to measure students' scientific creativity, with indicators of fluency, elaboration, flexibility, and originality. Furthermore, scientific creativity is measured based on seven dimensions, as presented in Table 2.

Table 2. Seven dimensions of scientific creativity.

No.	Dimensions	Aspects measured
1	Unusual use	Using objects with originality, fluency, and flexibility
2	Problem finding	Providing new questions from different perspectives
3	Product improvement	Having a goal to improve technical products
4	Creativity imagination	Scientific imagination
5	Problem solving	Problem solving ability
6	Science experiment	Experimental ability
7	Product design	Design ability

2.4. Data Analysis

After conducting normality and homogeneity tests, pretest and posttest data were analyzed using Jonckheere-Terpstra (J-T), Analysis of Variance (ANOVA), or the Kruskal-Wallis methods. Hypothesis testing was carried out with the following provisions:

1) If the Asymp. Sig value > 0.05, then H_0 (no difference) is accepted.
2) If the Asymp. Sig value < 0.05, then H_0 (no difference) is rejected.

With this method, the research can measure the effectiveness of PBBL in improving the scientific creativity of prospective science teachers.

3. RESULTS

The results of this research are presented in several sections, including the understanding and readiness of prospective science teachers towards ESD, readiness in developing eco-friendly 3D teaching aids, and the effectiveness of the PBBL method in improving students' scientific creativity.

3.1. Understanding and Readiness of Prospective Science Teachers for ESD

The understanding and readiness of prospective science teachers towards ESD are presented in Table 3.

Table 3. Understanding and readiness of prospective science teachers for ESD.

No.	Statement	The number of each statement	Maximum score	Percentage
1.	Self-understanding of ESD.	108	140	77.14%
2.	Self-readiness to integrate ESD in the production of learning aids.	117	140	83.57%
3.	Self-experience in implementing ESD in science learning.	89	140	63.57%
4.	Difficulty in integrating ESD into science learning.	88	140	62.85%
5.	Need for further guidance, guidelines, and training to overcome difficulties in integrating and implementing education for sustainable development in science learning.	126	140	90%
	Total	528	700	75.42%

Based on the results of students' responses regarding ESD understanding, prospective teachers have already understood the concept, as indicated by the response percentage of 77.14%. They are also ready to integrate ESD into science learning, as indicated by the response results of 83.57%. However, prospective teachers still have difficulty integrating and applying ESD in science learning, as evidenced by the response percentage of 62.85%. Therefore, they still require further instructions, guidelines, or training to overcome the difficulties of integrating ESD into science learning. Responses were also collected regarding the readiness of prospective teachers in developing eco-friendly-based 3D display tools, as presented in Table 4.

Table 4. Readiness responses of prospective science teachers in developing eco-friendly 3D teaching aids.

No.	Statement	The number of each statement	Maximum score	Percentage
1.	Self-understanding of eco-friendly 3D teaching aids.	83	140	59.28%
2.	Self-readiness to develop eco-friendly 3D teaching aids.	102	140	72.85%
3.	Self-experience in developing eco-friendly 3D teaching aids in science learning.	57	140	40.71%
4.	Difficulty in developing eco-friendly 3D teaching aids.	86	140	61.42%
5.	A need for further instructions, guidelines, and training to develop eco-friendly 3D teaching aids.	124	140	88.57%
	Total	452	700	64.57%

The 21st-century education requires prospective teachers to not only master pedagogical and content knowledge but also possess scientific creativity in designing solutions to real problems, specifically those related to environmental issues. The application of PBBL oriented toward eco-friendly principles can foster the development of scientific creativity. The results of N-gain scores for prospective teachers' scientific creativity are presented in Table 5.

Table 5. The average pre-test, post-test, and N-gain of students' scientific creativity in the three groups.

Group	Pre-test	Post-test	N-gain
1	27	48	0.75
2	16	46.50	0.78
3	18.50	46.50	0.74

Table 5 shows a significant increase in the average score of students' scientific creativity from pre-test to post-test in all three groups. Generally, N-gain in all groups is in the high category (g > 0.70), indicating that eco-friendly PBBL is effective in improving prospective teachers' scientific creativity. This suggests that a learning method involving an environment-based project can encourage students to think more creatively and scientifically in solving problems.

3.2. Effectiveness of Project-Based Blended Learning Method in Improving Students' Scientific Creativity

N-gain scores for scientific creativity in the three test groups are categorized as high. However, further testing is still needed to determine whether there is a consistent trend or pattern of changes in N-gain scores among the three groups. The test results are presented in Table 6.

Table 6. Jonckheere-Terpstra test results.

Test statistics a, b	N-gain score
Number of levels in group	3
N	110
Observed J-T statistic	1672.000
Mean J-T statistic	2001.500
Std. deviation of J-T statistic	181.640
Std. J-T statistics	-1.814
Asymp. Sig. (2-tailed)	0.070

Note: a. Jonckheere-Terpstra test.
b. Grouping Variable: Group (Replication 1, Replication 2, and Replication 3).

J-T test is used to detect whether there is a consistent trend or pattern of changes in N-gain scores among the three groups. The analysis results show an observed statistical value of 1672, with an average statistical value of 2001.500 and a standard deviation of 181.640. The standard value of the J-T statistic is -1.814, indicating a tendency for change, although with weak strength.

The two-sided asymptotic significance value of 0.070, greater than 0.05, indicates that although there is an indication of a difference in the impact of N-gain scores between groups, the results are not statistically significant. In other words, there is not enough evidence to state that the interventions administered to the three groups result in significantly different impacts on the pretest-posttest N-gain scores. There is a tendency for differences in the increase in N-gain scores between groups, but these differences are not strong enough to be considered significant. This suggests that the interventions given to the three groups have relatively similar impacts and do not show significantly different effectiveness in increasing the pretest-posttest N-gain scores. The results of the Kruskal-Wallis Test are presented in Table 7.

Table 7. Kruskal-Wallis test results.

Test statistics a, b	N-gain score
Kruskal-Wallis H	3.629
df	2
Asymp. Sig.	0.163

Note: a. Kruskal-Wallis test.
b. Grouping variable: Group (Replication 1, Replication 2, and Replication 3).

The Kruskal-Wallis test shows that the average rank for Groups 1, 2, and 3 is 62.55, 52.62, and 49.29, respectively. The test produces an H value of 3.629 with a degree of freedom (df) of 2 and a p-value of 0.163. Since the p-value is greater than 0.05, it can be concluded that there is no statistically significant difference in the median N-gain between the three groups. This indicates that the three groups have consistent levels of improvement in results without significant variation between groups.

4. DISCUSSION

The application of eco-friendly practices in PBBL is not only relevant in the context of sustainable education but also in encouraging prospective teachers' scientific creativity (Singha & Singha, 2024). These practices can be interrelated and mutually supportive. Eco-friendly refers to a method that minimizes negative impacts on the environment and focuses on sustainability in the learning process (Garrison & Kanuka, 2004). The application of eco-friendly practices in PBBL focuses on the use of projects that introduce environmental issues and the wise use of technology to support learning activities. Eco-friendly projects can involve making environmentally friendly products, researching environmental issues, or even efficient natural resource management activities. However, blended learning refers to the combination of face-to-face and online learning that allows for more efficient use of resources (Bangun, Degeng, Praherdhiono, & Lestari, 2023; Wahyudi & Winanto, 2018). In the context of eco-friendliness, the technology used in this type of learning can minimize the use of physical resources (such as paper or stationery), reduce the carbon footprint from travel, and provide students with access to learn various environmental management strategies online (Kaplan, 2013). The application of eco-friendly practices in PBBL is in the form of a project that involves the use of recycled materials in producing products. Online learning that allows students to learn from home reduces the need for physical transportation. The discussions on global environmental issues such as climate change, waste management, and renewable energy not only reduce the carbon footprint but also educate students about sustainability (Zhao, 2012).

PjBL still has several weaknesses, including: (1) it takes a lot of time to solve problems; (2) the method requires a lot of money; (3) there is a possibility that students are less active in group work; and (4) when the topics given to each group are different, students may not be able to understand the topics as a whole (Sholekah, 2020). During PBBL activities, students are given the problem of the limited availability of science teaching aids in schools. Furthermore, considering SDGs, they should create alternative innovations for science teaching aids with eco-friendly materials. The assessment of scientific creativity refers to seven dimensions, comprising unusual use, problem finding, product improvement, creative imagination, problem solving, science experiments, and product design. The first assessment related to unusual use requires students to identify various tools and materials that have the potential to become raw materials for science teaching aids by considering the impact on the environment. Students' creativity will be observed when providing answers in the form of various alternative tools and materials, specifically new and original ones. In the problem-finding assessment, students ask various questions related to the availability and suitability of teaching aids in schools. Creativity and metacognition processes are needed to identify problems correctly, making the problem-solving process run more effectively (Güner & Erbay, 2021; Urban & Urban, 2023).

Based on the observation results, in the product improvement dimension, students show various alternative ideas for improving teaching aids that can be carried out to enhance the quality of learning. The creative process at this stage will be evident when students identify opportunities from teaching aids by adding creative ideas that contain characteristics of novelty, originality, difference, uniqueness, effectiveness, meaningfulness, or meeting task constraints (Akpur, 2020; Pinkow, 2023). Creativity and imagination are assessed by asking students to describe the possible impacts on learning without using teaching aids. This evaluation process involves creativity in assessing ideas, identifying standards for teaching aids, predicting challenges, opportunities, and consequences of eco-friendly teaching aids in the future, and then refining their ideas into valuable concepts (Zhou et al., 2020). The previous questions will help students provide various alternative ways or steps in making eco-friendly teaching aids as a solution to science learning problems. As a problem-solving skill, creativity is observed in terms of building connections between concepts that seem unrelated to the problem, presenting new and non-conventional ways of solving environmental issues (Hujjatusnaini, Corebima, Prawiro, & Gofur, 2022; Moruzzi, 2021). The science experiment dimension is obtained from students' descriptions of science process skills, developed from the problem solutions that have been explained previously. Then, in the product design dimension, students provide the function of the teaching aids that have been designed comprehensively, and how they can offer benefits in eco-friendly science learning. Creativity in the context of the products produced refers to originality and meaningfulness, as well as how the products are used and accepted by the community (Ilha Villanova & Pina e Cunha, 2021).

Scientific creativity is the ability to think critically and innovatively to find solutions to complex problems. In the context of prospective teachers, this creative skill involves the ability to design and implement effective learning strategies, as well as to develop teaching methods that encourage students to think creatively and solve problems (Zhao, 2012). The application of eco-friendly practices in PBBL enhances the scientific creativity of prospective teachers by encouraging creative problem solving, the development of critical and divergent thinking skills, and the integration of interdisciplinary knowledge. In eco-friendly-based projects, prospective teachers and students are directly involved in identifying and solving problems related to sustainability. For example, in waste management or renewable energy projects, students are expected to design solutions that are not only innovative but also practical and eco-friendly (Cremin & Barnes, 2017). Eco-friendly-based projects require critical thinking skills to analyze the problems faced and find effective solutions. This stimulates divergent thinking skills, which are important in the development of scientific creativity among prospective teachers. The application of technology in blended learning allows prospective teachers to explore various resources and strategies that can enrich their creativity in designing PjBL (Runco & Acar, 2012). Eco-friendly principles in PBBL also lead to the integration of various disciplines, such as environmental science, technology, and education (Bower, 2019). The integration of these fields encourages prospective teachers to think holistically and creatively, and to find new ways to teach the material to students (Heilman, 2016).

This research shows a significant difference between the pretest and posttest results of students' scientific creativity. The increase in this creative skill in the moderate category is shown in Table 4. Meanwhile, the consistency of the increase is indicated by the results of the Kruskal-Wallis test in Table 7. PBBL provides facilities for students to be able to explore problems comprehensively and generate new ideas in solving them in effective and flexible ways. In the process, students can analyze problems, provide various alternative solutions, and assess these solutions by considering the values of sustainable development. Developing creativity in the classroom requires open-ended tasks that allow students to solve problems in a variety of ways and are relevant to their interests (Saimon, Lavicza, & Dana-Picard, 2023). Students' creativity is essential in performing these tasks, enabling them to provide innovative and original solutions. Previous analysis results show that PjBL can improve students' creativity, including scientific creativity and creative thinking skills (Chen, Lai, Lai, & Su, 2022; Lu, Lo, & Syu, 2022; Maros, Korenkova, Fila, Levicky, & Schoberova, 2023; Parwoto, Ilyas, Bachtiar, & Marzuki, 2024). The analysis has also shown that the involvement of technology, such as blended mode in learning, can support students' creativity (Bereczki & Kárpáti, 2021; Li et al., 2022; Wahyudi & Winanto, 2018). Various aspects of creativity are developed according to the technology used. The interaction between features in technology and students' thinking skills gives rise to activities that focus on the creative process (Bereczki & Kárpáti, 2021). Various creative processes that surfaced, such as creativity in initiating and sharing new ideas, are developed when students interact on social media. The media, in the form of applications with design features, can develop aspects of creative thinking (Li et al., 2022). The selection of eco-friendly themes in PjBL as a supporter of education for sustainable development plays a role in incr easing various positive emotions of students, such as enthusiasm, joy, and the level of satisfaction with the learning process (Hernández-Barco et al., 2021; Khamhaengpol, Nokaew, & Chuamchaitrakool, 2024). Furthermore, environmental-based learning that instills sustainable values directly can foster a connection to the environment and motivate students to adopt eco-friendly lifestyle (Begum et al., 2021). In the context of PjBL, the application of eco-friendly themes not only contributes to students' understanding of sustainability but also increases their scientific creativity. Scientific creativity manifests through the exploration and development of innovative solutions in the projects they undertake, such as creating 3D teaching aids based on eco-friendly materials. This aligns with students' responses to PjBL, which show positive feedback. The majority of students have understood the concept of ESD and are ready to develop eco-friendly 3D teaching aids, as shown in Table 3 and Table 4. The implementation of ESD encourages changes in knowledge, skills, values, and attitudes to enable a more sustainable and equitable society for all (Erlinawati, Dewi, Nugroho, & Roshayanti, 2024). ESD aims to empower and equip current and future generations to meet their needs using a balanced and integrated approach to the economic, social, and environmental dimensions of sustainable development (Khery, Sarjan, Nufida, & Ahzan, 2022). PjBL is a method that focuses on learning through hands-on experience. When combined with blended learning, eco-friendly PjBL becomes more flexible and widely accessible. In PjBL, prospective teachers work in teams to design and implement eco-friendly projects, encouraging them to think creatively to overcome various challenges. This method not only introduces scientific concepts theoretically but also provides space for experimentation and exploration that open up opportunities for the development of new creative ideas (Cremin & Barnes, 2017). Eco-friendly projects in PBBL support the development of problem-solving, critical thinking, and innovation skills, all of which are essential for enhancing scientific creativity. When prospective teachers engage in challenging solution-based learning, they learn to apply scientific theories in real contexts that are relevant to the environmental world (Clarke & Witt, 2019; Pérez-Escolar, Ordóñez-Olmedo, & Alcaide-Pulido, 2021). Universities have a strategic role in shaping students who are not only aware of sustainable development but also able to apply ESD values in scientific innovations that are oriented toward solutions.

5. CONCLUSION

In conclusion, the implementation of eco-friendly practices in PBBL significantly contributes to the improvement of prospective teachers' scientific creativity. By integrating sustainability principles into PjBL, prospective teachers learn to address environmental problems and develop the creative skills necessary to design and implement effective learning strategies. Eco-friendly projects, which utilize technology judiciously within blended learning environments, encourage students to think critically, collaborate effectively, and innovate. These elements are essential components in fostering scientific creativity in education. The adoption of PjBL and blended learning methods in higher education is recommended to support prospective teachers in designing eco-friendly 3D teaching aids. Furthermore, developing prospective teachers' professionalism is a strategic approach to enhancing teaching quality and improving teachers' perceptions of their professional status, job satisfaction, and self-efficacy, all of which contribute to sustainable education.

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