Asia Research Network Journal of Education
Vol. 5, No. 1, pp. 1-14, Jan – Apr 2025

Creative Thinking Skills of Science Teacher Candidates in Making Biobatteries through STEM Project Based Learning

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Received: 14 Dec 2024 Revised: 11 Jan 2025 Accepted: 18 Jan 2025

Abstract. This study aims to describe the creative thinking skills of prospective science teachers in making biobatteries through the Science, Technology, Engineering, Mathematic (STEM) integrated Project-based learning (STEM Pjbl) approach. This research was conducted in one of the Islamic universities in Indonesia involving 119 science teacher candidates. The students were formed into 20 groups of 5-6 members. A qualitative approach was used in this study to describe students' creative thinking skills. The research data were collected through observation, interviews during focus group discussions (FGDs), and logbook. The collected data were analyzed using the Creativity Product Analysis Matrix (CPAM) instrument. There are 3 dimensions of creativity that are assessed, namely novelty, resolution, and elaboration. The results showed that the creative thinking skills of science teacher candidates were 67.8% and classified as "good". The implementation of STEM Pjbl in making biobatteries has made students actively involved and able to develop their creativity. Therefore, this learning can be used as an alternative learning in higher education. This is because 1) prospective science teachers can explore and collaborate knowledge about the concepts of physics, chemistry, and biology and 2) can do hands on activities with their creativity.

Keywords: Creative thinking skills, biobattery, STEM PjBL

1. Introduction

The development of science and technology in various aspects of life has an impact on the competence of graduates (Toquero, 2021). Creative thinking skills are one of the essential abilities that must be possessed by prospective science teachers, especially in facing the challenges of the 21st century. Future teachers are expected to be able to create learning that not only focuses on knowledge transfer, but also encourages students to think critically, creatively, and innovatively. This is crucial because technological advances and global problems, such as the energy crisis and environmental damage, require creative solutions based on science and technology that are applied. Sural (2017) found that 293 prospective teachers realized the importance of 21st century skills but there was no improvement in those skills. However, various studies show that the creative thinking skills of prospective teachers in Indonesia are still relatively low, especially in the context of project-based learning that demands exploration and innovation.

One of the current global challenges is the need for environmentally friendly alternative energy. In this case, biobatteries are an important innovation because they utilize organic matter as a sustainable source of renewable energy. The introduction of biobattery technology through science learning is not only relevant to energy issues, but can also be an effective means to train the creative thinking skills of prospective science teachers. However, the use of project-based learning in the context of biobatteries is still minimal, so the potential for development has not been explored optimally. Some of the studies that have been found are: Listiowati et al. (2024) and Srivastava et al. (2024).

STEM PjBL (Science, Technology, Engineering, and Mathematics Project-Based Learning) learning is an approach that can support the development of creative thinking skills (Cengel et al., 2019a; Madyani et al., 2020; Prasetyo et al., 2022; Rahmawati et al., 2019a; Sutaphan and Yuenyong, 2023).This approach encourages students to integrate various disciplines in solving real problems, such as the manufacture of biobatteries. With STEM PjBL, prospective teachers not only learn science and technology concepts, but are also trained to develop creative solutions through the process of exploration, collaboration, and innovation (Baran et al., 2021b; Cengel et al., 2019b).

In the context of education for prospective science teachers, the application of STEM PjBL learning that focuses on making biobatteries has many benefits. In addition to improving a deep understanding of science concepts, this approach can also strengthen 21st-century skills such as critical thinking, collaboration, and communication (Rahmawati et al., 2019a, 2021). Biobattery manufacturing becomes a relevant and challenging project, as it involves the steps of design, testing, and evaluation, all of which require a high level of creativity.

This research is motivated by the urgent need to improve the creative thinking skills of prospective science teachers through an innovative and applied learning approach. This research focuses on exploring the ability to think creatively in making biobatteries through STEM PjBL learning. The results of this research are expected to make a significant contribution in designing effective learning models, improving the competence of prospective science teachers, and preparing them to become innovative and adaptive educators to the needs of modern education.

2. Theory

Biobatteries are energy storage devices that generate electricity using natural materials like plants, microorganisms, or organic waste. They function through a chemical reaction between the electrode and biological electrolyte, creating a flow of electrons. As an eco-friendly alternative to fossil-based batteries, biobatteries use renewable resources and are less harmful to the environment.

The main components of biobatteries are the anode, cathode, and electrolyte. In the anode, a chemical reaction releases electrons, while the cathode accepts them. The electrolyte, such as potato or fruit juice, conducts ions to support this reaction. This simple process makes biobatteries easy to teach and learn, even in schools.

Biobatteries are sustainable, cost-effective, and environmentally friendly due to the readily available materials. They also offer educational benefits, allowing students to explore electrochemistry and biology while developing creative problem-solving skills. Biobatteries, also known as microbial fuel cells (MFC), come in three types: single chamber (Aziz et al., 2013), dual chamber (Anam et al., 2020), and stack/multi-chamber (Estrada-Arriaga et al., 2017; Gajda et al., 2020) are shown in Figure 1a-c.

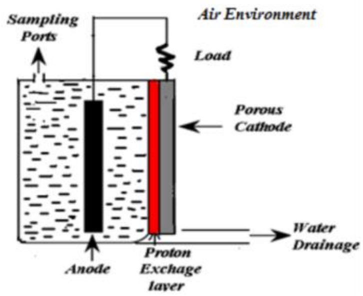

Figure 1a : Single chamber

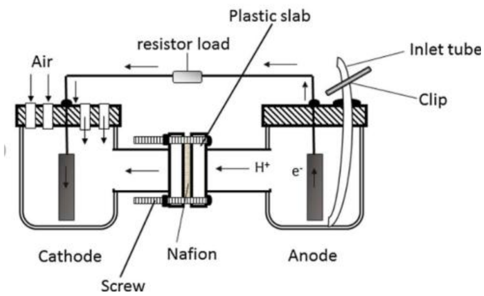

Figure 1b : Dual chamber

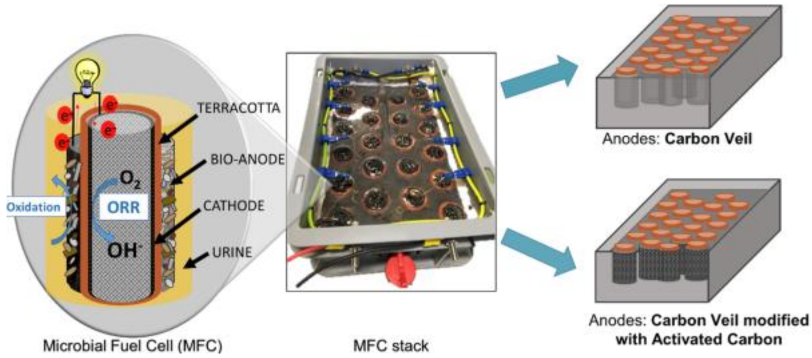

Figure 1c : Stack/multi Chamber

Everyone has different and unique creative abilities (Sternberg, 2003). If they exchange opinions and collaborate in groups, then they will be able to produce a monumental work. The actions to choose in creative thinking can vary according to the problem at hand. Those thoughts can influence in terms of limiting the problem, formulating a hypothesis, testing the hypothesis, and finally accepting or rejecting or changing the hypothesis (Demir Kaçan & Şahin, 2018; Hamid et al., 2021). In addition, students can create new ideas by using their experience (Rahmawati et al., 2019b, 2019a; Ridlo et al., 2020).Therefore, this research focuses on the creative thinking skills of science teacher candidates in making biobatteries through the implementation of STEM Project Based Learning. The dimensions of creativity studied are novelty, resolution, and elaboration (Hanif et al., 2019; Zulkarnain et al., 2024).

3. Methods

This research used a qualitative approach. The qualitative approach was used to describe the things that happened to the prospective science teacher students during project learning. Qualitative data were collected through observation, interview through focus group discussion (FGD), and logbook. Each group documents every activity carried out including progress and obstacles or anything experienced in the form of a logbook. Narrative research design was used in this study. This method is by describing things that happen during learning, then documenting, and explaining stories about student experiences in the form of narrative. (J.R Fraenkel et al., 2012). In collecting data, the researcher acted as a non-participant. The researcher only supervised and observed classroom activities and was not directly involved in the observations. Observation, interview, and logbook data of each group were analyzed based on CPAM instruments (Table 1). After that, the category of creative thinking skills is determined through percentages (Table 2).

4. Population and Sample

This research was conducted to observe prospective science teacher students at one of the Islamic universities in Indonesia in the 2018/2019 academic year. The research subjects consisted of 119 prospective students registered in the Natural Sciences (IPA) teacher education program, with details of 35 male students and 84 female students. For sampling, a saturated sample technique was used, in which all members of the population who met the research criteria were included without exception (J.R Fraenkel et al., 2012). Therefore, all prospective students enrolled in the program in the 2018/2019 academic year are part of this research sample. The learning in this study was carried out using a group-based learning method. Each group consists of male and female students to ensure diversity and balanced interaction. Each group consists of 5 to 6 students, which is designed to facilitate effective discussion and cooperation. With a total of 119 students, 20 study groups were formed. This group learning aims to encourage collaboration between students, improve teamwork skills, and deepen their understanding of the science concepts taught (Efendi et al., 2023). Through interaction between group members, it is hoped that students can exchange knowledge and enrich their understanding of the material studied.

5. Research Instruments

The Criteria Product Analysis Matrix (CPAM) is a tool used to evaluate and analyze products based on specific criteria. This tool helps in clarifying important aspects of the product or design that is being developed, so that the design team can focus on the crucial details. CPAM is often used in the context of product development, design, or project evaluation, with the aim of providing a clearer understanding of product quality, value, and potential (Tsai, 2016).

CPAM is arranged in the form of a matrix consisting of columns containing evaluation criteria and rows that represent the product or design alternative being analyzed. The criteria used for evaluation may vary. Each of these criteria is then assessed using a specific scale or weight, which helps to measure how well each product meets the desired standard.

The Creativity Product Analysis Matrix (CPAM) instrument was used to obtain qualitative data. The instrument was adopted from Besemer & Treffinger (1981). Student creativity data obtained during the learning process was categorized with a range of values from 1 to 3. Value 1 indicates "Low" creativity, value 2 indicates "Medium" creativity, and value 3 indicates "High" creativity. The aspects of creativity assessed consisted of: 1) novelty, 2) resolution, and 3) elaboration. In addition, each aspect has criteria contained in the CPAM assessment rubric and shown in Table 1.

Germinal and Original criteria are used as dimensions to assess novelty. Germinal criteria refer to the ability of a product to be the basis for the development of other creative products in the future. Instead, the uniqueness criterion relates to how rare a product is when compared to other products that have similar ideas and provide a similar experience. For the Resolution dimension, the selected criteria are Useful and Valuable. Value criteria reflect how others perceive a product as something that meets an economic, physical, social, or psychological need. Meanwhile, useful criteria emphasize the clarity and practicality of the product in its use. Finally, for the Elaboration dimension, the Well-crafted and Expressive criteria are selected. This criterion assesses the extent to which the product is designed with good details and is able to express ideas effectively. In addition, the last criterion chosen for the elaboration dimension is well-crafted and expressive. A well-crafted criterion refers to the quality of the product's appearance as well as the extent to which it has been meticulously designed, improved, or modified from its original idea. Meanwhile, expressive criteria assess the extent to which a product is able to convey a message or idea effectively. This criterion stipulates that the product must be presented clearly and communicatively (Hanif et al., 2019; Zulkarnain et al., 2024).

Table 1: Instruments for Creativity Product Analysis Matrix (CPAM)

Dimensions of creativity	Criteria	Score		
		1 (low)	2 (medium)	3 (high)
Novelty	Germinal	This product inspires others	The product inspires others and tries new things	It inspires other, tries new things, and gives ideas for developing other products
	Original	Most prospective science teachers duplicated product ideas from previous findings	The prospective science teachers used the previous findings as a base idea, but modified them	Product ideas come from the science teacher candidates' own understanding
Resolution	Valuable	Product is not compatible with the objective and relates to the concept	Product is compatible with the purpose and not related to the concept	Product is compatible with the objectives and relates to the concept
	Useful	Product can be used once only	The product can be used multiple times under certain conditions	The product can be use multiple times without conditions
Elaboration	Well crafted	Product is well done	Well done product with good design	Students are use several materials to design attractive products
	Expressive	The product presented is not understandable	The product presented is understandable	Product presented in a communicative and understandable manner

Table 2: Interpretation of students' creative thinking skills

Percentage (%)	Interpretation
81 – 100	Very good
61 – 80	Good
41 – 60	Sufficient
21 – 40	Bad
0 – 20	Very bad

The CPAM model can be used to explore possible similarities and differences between the understanding of the two groups (Chien et al., 2023). Products from students that have been assessed based on the CPAM instrument, then made a percentage. The percentage results were interpreted based on Table 2 so that the categories achieved by students could be known (Madyani et al., 2020). Divided the categories of creative skills into 5, namely: very good, good, sufficient, bad, and very bad.

6. Research Procedure

The stages of STEM Project-based learning consist of preparation, implementation, presentation, evaluation, and correction (Baran et al., 2021a). A description of the activities of each stage can be seen in Table 3.

Table 3: Stage of STEM Project Based Learning

Meeting	Stages	Activities
1	Preparation	Students understand the theme of the project
		Students search the internet for relevant findings
		Students discuss the tools and materials and their design to create this project
		Students draw product designs
2	Implementation	Students work on the project based on the design that has ben made
		Students test the products they have made
3	Presentation	Each other group presents their product
4	Evaluation	Lecturers and other students evaluate the products presented
5	Correction	The group corrects their product based on feedback

The project implementation process consists of five main stages designed to ensure quality deliverables and in-depth learning for students. The first stage is **Preparation**. At this stage, students start by deeply understanding the theme of the project to be worked on. They then searched for information from various sources, including the internet, to obtain findings and references relevant to the project. After that, the design is outlined in the form of drawings that are the main guide in the implementation of the project. The second stage is **Implementation**. At this stage, students begin to realize the design that has been made before. With good collaboration in groups, they work together to create products as per the design. Once the product is finished, students test it to ensure that it works as expected. After the product is completed, the project proceeds to the **Presentation** stage. In this stage, each group is given the opportunity to present their work in front of other groups. This presentation includes an explanation of the manufacturing process, product functions, and benefits. The fourth stage is **Evaluation**. Lecturers and other students who attended provided criticism, suggestions, and input on the products presented. The last stage is **Correction**. Based on the feedback received, each group made revisions and improvements to their products. This improvement process allows students to apply the input that has been given, so that the final result becomes better and in accordance with the project objectives.

7. Results and Discussion

This study describes the process of making biobatteries through STEM learning Pjbl. Prospective science teachers work in teams to design, implement, and test the electricity of biobatteries. In addition, they also have to think about using the tools and materials around them. In meeting 1, the lecturer explained the material about 1) renewable energy, 2) living things have the potential to be a source of electrical energy, and 3) biobatteries. Then, students in the team were given the opportunity to search for relevant references from the internet. The search for references certainly does not stop in the classroom. They are still looking for references outside the classroom. The students face difficulties in finding the various information needed to solve the problem in their project. They realize that the internet provides many sources of information, but not all of them can be considered valid. Therefore, they not only learn to search for information, but also develop the ability to evaluate its accuracy and relevance. This is in line with what Rahmawati et al. (2019a) found. Judging from the logbook they made, students looked for references from journals, google, and youtube. Based on this, they already have the ability in terms of *Technology*. At this stage will indicate "novelty". Are they just duplicating/modifying/actually emerging ideas from them.

After finding tools, materials, containers, in meeting 2, students implemented their findings. At this stage, students make a substrate container, prepare the substrate, a salt bridge (if it is a dual chamber), and electrical Measurement (Figure 2).

Preparing the substrate **Container manufacturing** **Electrical Measurement**

Figure 2

At this stage, students will have various problems, for example: "leaking containers in the salt bridge area". The solution is to "re-glue the salt bridge area with wax glue and black duct tape". Being able to use these tools shows that they have mastered *Engineering* skills. This shows that they have good problem-solving skills. Through hands-on and group activities, problem-solving skills can emerge (Rahmawati et al., 2019a)

After the product is finished, it is electrically tested using a multimeter. At this stage, you will see the "elaboration" aspect. Of the criteria well crafted: Product is well done/ Well done product with good design/ Students are use several materials to design attractive products and of the criteria expressive: The product presented is not understandable/The product presented is understandable/Product presented in a communicative and understandable manner. Calculating the voltage or current using an analogue multimeter and making a graph of the relationship between variables is the *Mathematic* aspect of this research. The biobattery that has been made by each group based on the main material and maximum voltage is shown in Table 5.

Table 5: The main ingredients of the biobattery and the voltage produced by each group

Group	Main Ingredients	Maximum mains voltage (V)
1	Guava	4,62
2	Cucumber	1,76
3	Tomatoes	0,22
4	Lime	1,8
5	Noni	1,8
6	Kaffir lime	0,2
7	Potatoes	3,08
8	Cassava, Banana Peel, Kaffir lime	2,4
9	Starfruit	12
10	Rotten tomatoes	10
11	"Raja Nangka" banana peel	1,19
12	Cow manure and water hyacinth	0,87
13	Detergent waste mixed with husk ash	0,77
14	Pamelo Orange peel	1,43
15	Gadung Tuber (*Dioscorea hipsida*)	0,8
16	Liquid Fertilizer and Eco Enzyme	12
17	Liquid tofu waste	0,4
18	Star fruit	3,5
19	Rice washing water and salt water	0,63
20	Cow dung, water, and salt	8

In meeting 3 and 4, each group presented the progress that had been made. In addition, they also conveyed science in the manufacture of biobatteries. The *Science* concepts discussed by students in making biobatteries consist of physics, chemistry, and biology concepts. The physics concepts discussed are: resistance, current, and voltage. The chemical concepts discussed are redox reactions and electrolyte substances. The biological concepts discussed are: aerobic and anaerobic respiration. The interconnection of these concepts is the basis for students in constructing biobatteries that can produce large currents or voltages (Figure 3). At this stage, students share experiences and also get input from lecturers and other groups. If they are still not satisfied with the results, they are given the opportunity to repeat again.

Figure 3 Students present biobatteries that have been made

In meeting 5, the group corrects their product based on feedback. At this stage, the logbooks that have been created are collected for evaluation. The process of making biobatteries that have been analyzed in science, technology, engineering, and mathematical (STEM) aspects is shown in Table 4.

Table 4: STEM integration in biobattery manufacturing

Science (S)	**Technology (T)**	**Engineering (E)**	**Mathematics (M)**
Electrical Resistance	Search for information / previous research related to biobatteries on internet	Designing a biobattery assemble tools and materials weighing ingredients	Calculating the magnitudes
Electric Current			
Electrical Voltage			Graph the relationship between variable
Redox reaction			
Voltaic series		Measure electrical current and voltage using a multimeter	
Aerobic Reaction	Measuring tools and materials to be used in the manufacture of Biobatteries		
Anaerobic Reaction			

The results of observations and interviews were compared with logbooks and the average score of creative thinking skills was obtained as shown in Figure 4. The average values of novelty, resolution, and elaboration obtained were 70%; 67.5%; and 65.8%, respectively, with an overall average value of 67.8%. The percentages that have been obtained are categorized based on Table 2.

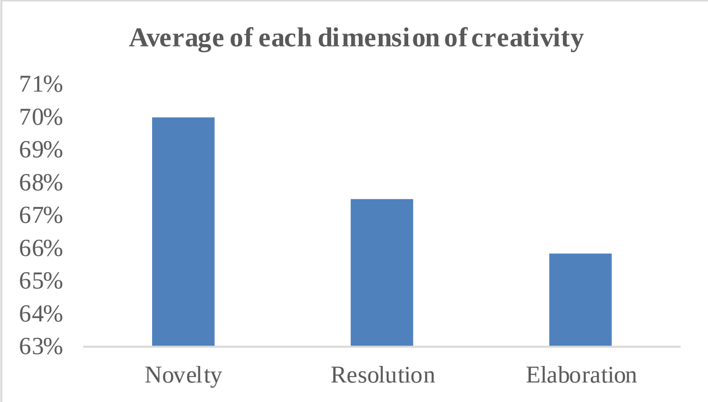

Figure 4 Graph of the average score of the creativity dimension achievement

This shows that student creativity is categorized as "medium". The aspect of "novelty" got the highest achievement, while the aspect of "elaboration" got the lowest achievement. Details of the acquisition of the number of groups that scored 1-3 in each dimension of creativity are shown in Table 6. In general, prospective science teacher students find it easier to modify the biobattery research that has been found including modifying tools, materials, and designs. The reason for the low "elaboration" dimension is that many groups scored "1" in the "well-crafted" criteria. This shows that they are more focused on the success of making the product without paying attention to the appearance.

Table 6: The number of groups that received a score of 1-3 in each dimension of creativity

Creative dimension	Criterion	Number of groups scored		
		1	2	3
Novelty	Germinal	6	7	7
	Original	5	7	8
Resolution	Valuable	3	13	4
	Useful	0	20	0
Elaboration	Well crafted	9	10	1
	Expressive	0	13	7

While making the biobattery, each group recorded the obstacles they experienced each day. In addition, they also recorded the problem solving that had been done in overcoming the obstacles. At the presentation stage, groups that experienced obstacles received input from their peers and lecturers. The analysis of the achievement of each dimension of creativity for each group is shown in Figure 5.

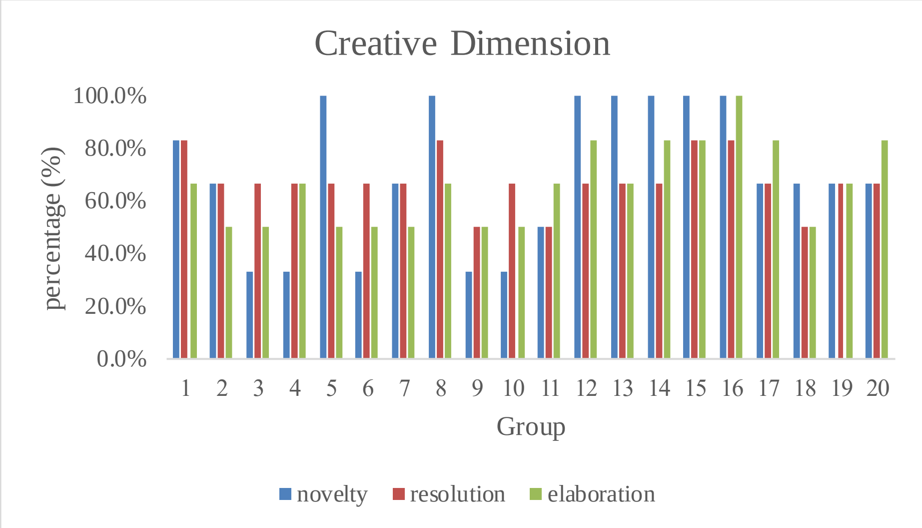

Figure 5: Dimension of creativity of each group

Group 16 scored the highest overall average among the others. From their initial process in preparing electrolyte substances carefully by fermenting vegetable and fruit waste (Figure 6a-c). Leachate from fruit and vegetable waste was mixed with water and palm sugar to make "eco enzyme". This material is used as the electrolyte for making biobatteries.

Figure 6a: Vegetable and fruit waste

Figure 6b: Vegetable and fruit waste after 2 weeks

Figure 6c: Leachate water from vegetable and fruit waste

With a multi-chamber design, eco enzymes are used as electrolytes. A used milk container was used as the container. Then, the substance was coupled with brass and zinc electrodes. Afterwards, the voltage was measured using an analogue multimeter. This process is shown in Figure 7a-c.

Figure 7a: electrode installation

Figure 7b: biobattery placed in a box

Figure 7c: voltage measurement on product

With the STEM PjBL approach, it can provide space for students to develop creativity and active enquiry (Rahmawati et al., 2019b). This result is certainly a positive thing for teachers and students. Creative thinking as logical and divergent thinking to produce something new. This is important in the industry 4.0 era for prospective science teachers. Science learning is also expected to make graduates who are able to interact with nature and society.

8. Conclusion

The creativity of science teacher candidates in making biobatteries through STEM Project-based learning is categorized as "good" with an average score of 67.8%. Through this learning, prospective science teacher students have been able to explore natural ideas/potential well. This is evidenced by the high creativity dimension "novelty" of 70%. On the other hand, the "elaboration" dimension still gets a low score of 65.8%. However, making biobatteries through STEM Project based learning can be used as an alternative learning for prospective science teachers. This is because 1) prospective science teachers can explore and collaborate knowledge about the concepts of physics, chemistry, and biology and 2) can do hands on activities with their creativity.

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