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The Effect of Project-Based Learning with a STEM Approach on Students Creative Thinking Ability and Science Process Skills

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Abstract: Creative thinking ability is one of the essential demands of 21st-century learning, which needs to be supported by science process skills to foster deeper understanding and meaningful learning experiences. However, science learning in schools is still largely dominated by lecture methods with minimal practical activities, resulting in students being less active, untrained in creative thinking, and rarely engaged in scientific processes. This study aims to investigate the effect of the Project-Based Learning (PjBL) model with a STEM (Science, Technology, Engineering, and Mathematics) approach on students' creative thinking ability and science process skills in the topic of elements, compounds, and mixtures. The research employed a quasi-experimental method with a pretest-posttest control group design for creative thinking ability and a posttest-only control group design for science process skills. The sample consisted of two eighth-grade classes selected through random sampling, with 30 students in each class. One class was assigned as the experimental group, taught using the STEM-based PjBL model, while the other served as the control group using conventional instruction. Research instruments included essay tests and observation sheets. Data analysis using the t-test revealed a significant effect on creative thinking ability ($p = 0.001$, $p < 0.05$) and science process skills ($p = 0.004$, $p < 0.05$). The novelty of this study lies in the integration between the design of PjBL and the STEM approach, with systematic measurement of two important indicators of 21st-century learning: creative thinking and science process skills, in the context of applied basic chemistry topics. Thus, the findings affirm that integrating PjBL with STEM is effective in fostering 21st-century skills. Based on these results, it is recommended that innovative and contextually relevant projects be designed to support the development of meaningful science learning.

Keywords: Conventional Learning; Creative Thinking Skills; Project-Based Learning; Science Process Skills; STEM.

Introduction

21st-century education requires students to possess higher-order thinking skills such as critical, creative, collaborative, and communicative thinking [1]. [2] emphasize that to face the challenges of this era, education needs to focus on strengthening critical, creative, and collaborative thinking skills, so that students are prepared to deal with complex and dynamic changes. In the context of science learning, creative thinking ability is one of the essential competencies because it encourages students to generate new and innovative ideas to solve problems [3]-[4]. In addition, science process skills are also a crucial aspect as they highlight the ability to use scientific methods to acquire knowledge systematically [5]-[6].

However, observations at SMP Negeri 17 Medan revealed that science learning on the topics of elements, compounds, and mixtures remains oriented toward lectures and exercises, and has not been effectively linked to real-life contexts. As a result, students become passive, less engaged in the learning process, and struggle to develop ideas independently. Preliminary research findings also revealed that students' creative thinking ability is still relatively low, with an average score below 50%. Some students were able to answer questions, but without sufficient reasoning and argumentation, indicating weaknesses in the flexibility and elaboration aspects of creative thinking [7]

On the other hand, laboratory activities are rarely conducted, so students only understand concepts theoretically rather than through direct experience. This has an impact on science process skills that have not yet developed optimally [8]-[9]. To address these problems, a learning model that is contextual, experience-based, and capable of simultaneously training creative thinking and science process skills is needed.

One of the models proven to be effective is Project-Based Learning (PjBL), a project-based learning approach that encourages students to actively develop products as solutions to problems [10]-[11]. This approach provides students with opportunities to think flexibly and generate original ideas at every stage of the project. Research by [12] shows that PjBL can improve the fluency and flexibility aspects of students' creative thinking. In addition, PjBL also makes a significant contribution to enhancing science process skills [13].

Furthermore, the integration of the STEM (Science, Technology, Engineering, and Mathematics) approach into PjBL is believed to create more meaningful and contextual learning. STEM combines various disciplines to solve problems in an applied manner, connecting science concepts with the real world [14]. Pfeifer, Ignatov, and Poelmans emphasize that in STEM learning, knowledge

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and skills from various disciplines are applied simultaneously to solve problems comprehensively and applicably [15]. Previous studies have shown that the STEM approach can strengthen creative thinking and develop collaborative and problem-solving skills [16]-[17]. Nevertheless, the implementation of PjBL-STEM in practice still faces challenges, particularly in the project planning stage and in achieving comprehensive integration of STEM concepts [18]-[19].

Although several studies have discussed the effectiveness of Project-Based Learning (PjBL) and the integration of the STEM approach in improving students' creative thinking and science process skills, most of them have focused on topics related to physics or engineering design at the high school level. Only a few studies have examined its application to basic chemistry topics such as elements, compounds, and mixtures at the junior high school level. In addition, previous research has not yet provided a comprehensive assessment that simultaneously measures creative thinking and science process skills within the same integrated learning framework. Furthermore, some studies reported that the early stages of project implementation, particularly reflection and project determination, were still not optimal, resulting in limited development of students' creative ideas (Mamahit et al., 2020; Saefullah et al., 2021; Hikmah et al., 2024; Restiana et al., 2024). Therefore, this study seeks to address these gaps by implementing a more structured and contextual PjBL-STEM model and by systematically evaluating its impact on students' creative thinking and science process skills.

Based on these conditions, this study focuses on the application of the Project-Based Learning model with a STEM approach in teaching the topic of elements, compounds, and mixtures in junior high school. This research aims to analyze the effect of this model on students' creative thinking ability and science process skills. The novelty of this study lies in the integration between the design of PjBL and the STEM approach, with systematic measurement of two important indicators of 21st-century learning: creative thinking and science process skills, in the context of applied basic chemistry topics. The results of this study are expected to contribute to the development of innovative learning strategies at the junior high school level and enrich the literature related to the comprehensive implementation of PjBL with the STEM approach.

Research Methods

The research was conducted at SMP Negeri 17 Medan during the even semester of the 2024/2025 academic year. The study population comprised all eighth-grade students, totalling 319 individuals, from which two classes were selected through random sampling: class VIII-10 as the experimental group and class VIII-8 as the control group. The experimental group received instruction using the STEM-based Project-Based Learning model, while the control group was taught through conventional methods.

The research instruments included essay tests to measure creative thinking ability based on Torrance's indicators (fluency, flexibility, originality, elaboration), as well as an observation sheet containing 12 items to evaluate six indicators of science process skills. All instruments were validated by experts prior to use. The subject matter in this study was elements, compounds, and mixtures.

This study employed a quantitative approach with a quasi-experimental design. Two forms of design were employed to accommodate the characteristics of each variable: the pretest–posttest control group design for creative thinking ability and the posttest-only control group design for science process skills.

Table 1. Desain penelitian pretest-postest control group

Group	Pre-test	Treatment	Post-test
Eksperimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

(Source [20])

Description:
O_1: Pre-test of creative thinking skills given to the experimental and control classes before the treatment.
O_2: Post-test of creative thinking skills given to the experimental and control classes after the treatment.
X_1: Treatment using the Project-Based Learning (PjBL) model integrated with the STEM approach.
X_2: Treatment using conventional learning (lecture and question-and-answer).

Table 2. Desain penelitian posttest-only control group

Group	Treatment	Post-test
Eksperimental	X_1	O_3
Control	X_2	O_3

(Source [20])

Description:
X_1: Treatment consisted of learning using the Project-Based Learning (PjBL) model with a STEM approach.
X_2: Treatment consisted of conventional learning (lecture and Q&A).
O_3: Post-test of science process skills given to the experimental and control classes after the treatment.

The difference in research design was adjusted to the nature of each variable. Creative thinking ability is a cognitive skill, so it was measured using an essay test administered before and after the treatment to determine improvement. In contrast, science process skills are psychomotor in nature and were observed directly during learning activities; therefore, assessment was carried out after treatment through observation. Despite the difference in data collection, both designs are based on a quasi-experimental approach involving experimental and control groups, allowing the results to be compared equivalently.

The research procedure consisted of three stages: (1) the preparation stage, which involved preliminary observations, teacher interviews, sample selection, and instrument validation; (2) the implementation stage, which included pre-test administration, treatment application, classroom observations during learning activities, and post-test administration; and (3) the final stage, which involved data collection and analysis.

Data were analyzed using SPSS version 30 through several steps: normality test (Shapiro–Wilk), homogeneity test (Levene's Test), and hypothesis testing using a one-tailed independent sample t-test to determine the effect of the treatment on students' creative thinking ability and science process skills. This analytical technique was used for both variables because the aim was to compare the results between the experimental and control groups. However, the types of data analyzed were different test scores for creative thinking ability (pretest and posttest) and observation scores for science process skills (posttest only).

Results and Discussion

Creative Thinking Ability

The t-test yielded a significance value of 0.001 < 0.05, confirming a significant difference between the two classes. This improvement demonstrates that the implementation of the Project-Based Learning (PjBL) model with a STEM approach had a positive effect on students' creative thinking skills. This finding aligns with [21], who argues that PjBL provides opportunities for students to explore solutions, think critically and creatively, and engage in meaningful learning experiences.

Data on creative thinking skills were obtained through pre-test and post-test administrations in both the experimental and control classes. The average pre-test score in the experimental class was 30.04, while the control class achieved a score of 29.91, indicating comparable initial conditions. After the intervention, the average post-test score in the experimental class increased significantly to 50.12, whereas the control class only reached 37.08 (Figure 1).

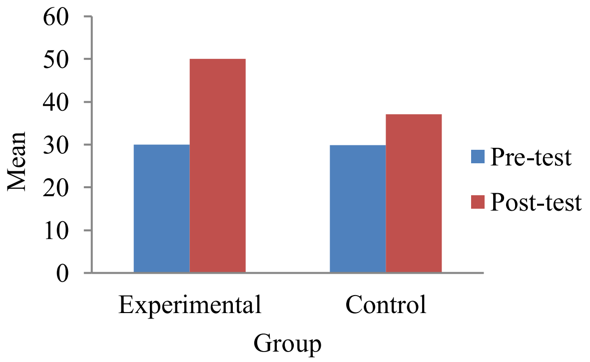

Figure 1. Mean Scores of Pre-test and Post-test of Eighth-Grade Students Creative Thinking Ability Between the Experimental and Control Groups on the Topic of Elements, Compounds, and Mixtures.

Significant improvements were also observed across all creative thinking indicators in the experimental class (Figure 2). Fluency increased from 32.16 to 61.16, flexibility from 31 to 48.16, originality from 28 to 47, and elaboration from 29.16 to 44.5. These results are consistent with [22], who emphasized that creativity can be fostered through challenging, project-based activities that encourage learners to generate original ideas.

By contrast, the control class exhibited only marginal improvement (Figure 3). For example, flexibility increased from 31.33 to 35, and originality from 27 to 35. This condition reflects the limitations of conventional teaching methods in nurturing creativity. Similar observations were reported by [23]-[24], who noted that traditional approaches tend to render students passive and provide fewer opportunities for divergent thinking.

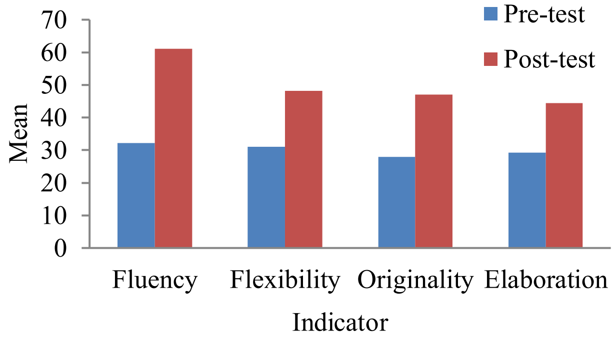

Figure 2. Mean Scores of Pre-test and Post-test Indicators of Creative Thinking Ability of Eighth-Grade Students in the Experimental Group on the Topic of Elements, Compounds, and Mixtures.

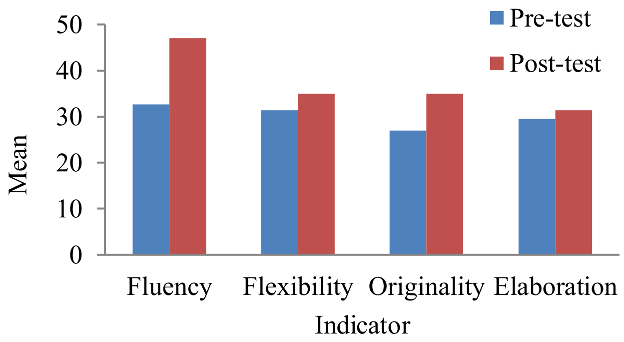

Figure 3. Mean Scores of Pre-test and Post-test Indicators of Creative Thinking Ability of Eighth-Grade Students in the Control Group on the Topic of Elements, Compounds, and Mixtures.

Furthermore, the product assessments of students in the experimental class (Figure 4) revealed that most groups were able to produce innovative works, including natural cleaning solutions, fabric dyes, waxing products, and aromatherapy candles. These products reflect the integration of science, technology, engineering, and mathematics, while also highlighting differences in collaborative skills and depth of conceptual understanding among groups.

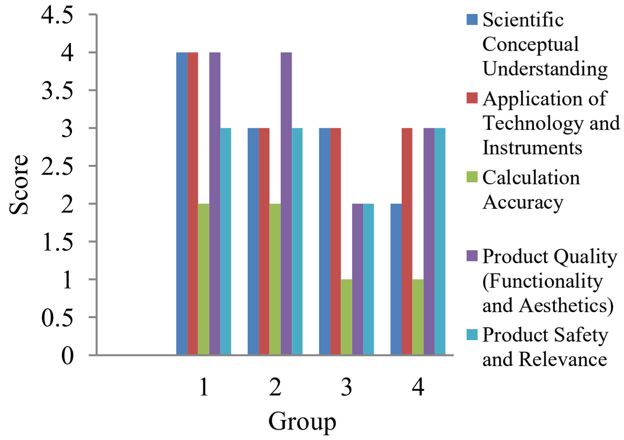

Figure 4. Product Assessment of Experimental Class Students on the Topic of Elements, Compounds, and Mixtures.

These results indicate that the implementation of the PjBL model with a STEM approach encourages most students to produce products that not only have practical functions but also reflect the integration of concepts related to elements, compounds, and mixtures, as well as the use of simple technology, mathematical calculations, and a structured product design process. The variation in product quality among groups reflects differences in the depth of understanding, collaborative skills, and the ability to apply STEM components comprehensively. These findings are consistent with the studies of [25]-[26], which emphasize that project-based learning with a STEM approach can foster students' critical, productive, and systematic thinking skills in creating meaningful, functional, and safe products that apply scientific and technological concepts.

Science Process Skills

The t-test yielded a significance value of 0.004 < 0.05, indicating a statistically significant difference between the two groups. This suggests that the application of the PjBL model with a STEM approach has a positive influence on students' science process skills. Science process skills develop optimally through the implementation of PjBL with a STEM approach, which encourages students' active involvement in the scientific process, starting from asking questions, observing, conducting experiments, and communicating results [27]-[28].

Science process skills were measured through classroom observations during practical activities. The results revealed that the experimental class achieved a higher average score (63.11) compared to the control class (53.88) (Figure 5).

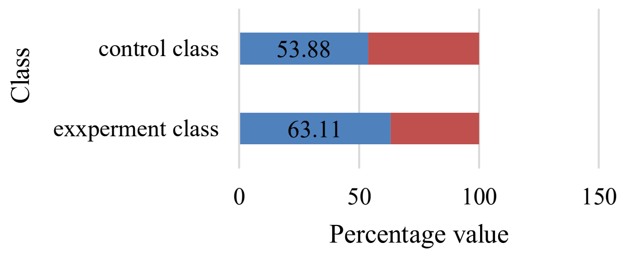

Figure 5. Differences in Post-test Scores of Science Process Skills of Grade VIII Students Between the Experimental and Control Classes on the Topic of Elements, Compounds, and Mixtures.

Indicator analysis (Figure 6) revealed that the experimental class outperformed the control class in all aspects, particularly in questioning (68.33%), followed by processing (61.25%), evaluating (65%), and communicating results (65%). These findings suggest that PjBL, combined with a STEM approach, engages students across the full spectrum of scientific inquiry, from observation and experimental design to the communication of results. Project-based learning effectively enhances science process skills by fostering direct student engagement in experimental tasks [29]-[30].

Conversely, students in the control class demonstrated lower levels of science process skills, particularly in planning (53.75%) and evaluation (52.08%). Students tended to rely heavily on teacher guidance and showed limited ability to critically reflect on experimental outcomes. Science process skills develop more effectively when students are engaged in authentic projects that encourage exploration and collaborative discussion [31].

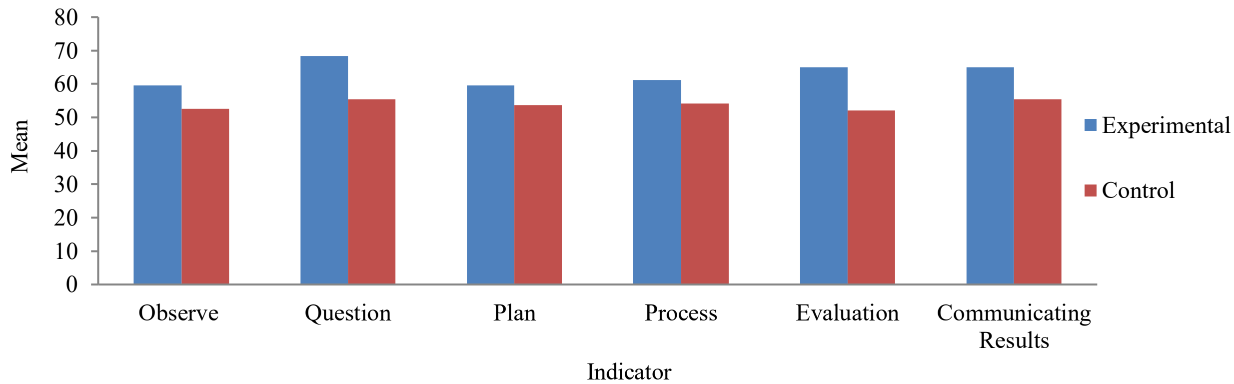

Figure 6. Post-test Mean Scores of Science Process Skills Indicators of Grade VIII Students in the Experimental and Control Classes on the Topic of Elements, Compounds, and Mixtures

The implementation of the Project-Based Learning (PjBL) model with a STEM approach demonstrated a significant improvement in students' science process skills; however, several stages of the PjBL syntax were not optimally executed. The stages of project design and independent project implementation continued to be challenging for some students. This was evident from the tendency of several groups to rely on teacher instructions when determining experimental steps or selecting methods of mixture separation, resulting in limited diversity and innovation in their ideas. During the reflection and project evaluation stage at the end of the lesson, not all groups were able to identify procedural weaknesses or formulate in-depth recommendations for improvement. Several factors contributed to this situation, including limited laboratory time, differences in students' initial readiness regarding scientific process skills, and insufficient availability of materials and equipment. In line with the implementation of PjBL with a STEM approach, resource limitations and teacher readiness often constrain the optimal execution of stages such as project design, independent implementation, evaluation, and reflection studies [32]-[33]. This condition highlights the need for more intensive scaffolding strategies during these stages to ensure more effective PjBL implementation. In this study, efforts to optimize the design, implementation, and reflection stages were made by providing project-based student worksheets (LKPD) and offering additional guidance during the design and implementation phases. Nevertheless, these measures were not fully successful due to time constraints and students' limited experience, indicating that further improvement is needed in future research. Previous studies have shown that PjBL-STEM, accompanied by teacher facilitation and inter-cycle reflection, can help enhance the project design and reflection stages, even though the process may not always be flawless [34]-[35].

Conclusion

The implementation of the Project-Based Learning (PBL) model with a STEM approach has been shown to have a positive impact on enhancing students' creative thinking skills and science process skills in learning about elements, compounds, and mixtures at the junior high school level. Students who participated in learning through the STEM-based PjBL model demonstrated higher levels of creative thinking and science process skills compared to those who received conventional instruction. This learning model offers students opportunities to explore scientific concepts through hands-on experiences, create products that address real-world problems, and integrate elements of science, technology, engineering, and mathematics in a cohesive manner. PjBL with a STEM approach effectively bridges conceptual learning with its application in everyday life, encouraging students to think more flexibly, creatively, and systematically. Therefore, this model can serve as an effective instructional strategy to enhance the quality of science learning and foster students' 21st-century skills.

Author's Contribution

Tri Fitri Cahyati Sidabutar: Responsible for research design, data analysis, and completion of scientific article writing. Ely Djulia and Marlina Sinaga: Providing constructive suggestions to improve the writing.

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