



Deep Learning through a STEM-Integrated Project-Based Learning Model for Enhancing Students' Creativity

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Abstract: 21st-century education demands that students not only master basic knowledge but also develop critical, creative, and problem-solving skills. These skills can be enhanced through Project-Based Learning (PjBL) integrated with STEM within a deep learning framework. This qualitative case study involved 11th-grade students at SMAN 1 Simpang Tiga, using observations, interviews, and project document analysis, with data analyzed via the Miles and Huberman's interactive model. The findings reveal that STEM-integrated PjBL creates an open, contextual learning environment that encourages active idea exploration, diverse perspectives, and interdisciplinary projects combining science, technology, engineering, and mathematics, leading to deep problem-solving. The model also fosters greater student enthusiasm and emotional engagement throughout the learning process. This study suggests that integrating PjBL-STEM in deep learning effectively builds a collaborative, reflective, and creative learning culture. Additionally, it highlights the crucial role of teachers as facilitators who design authentic, meaningful learning experiences that stimulate student creativity.

Keywords: 21st-century skills; Creativity; Deep learning; PjBL; STEM integration

Introduction

The development of education in the 21st century demands that students possess higher-order thinking skills, which include critical thinking, communication, collaboration, and creativity (Herlinawati et al., 2024). Among these competencies, creativity holds a key position as it serves as the foundation for innovation and adaptive capacity in responding to the rapid changes of the modern era. In the context of science learning, creativity is not only related to the ability to generate new ideas but also to the capacity to apply scientific concepts in new situations, solve problems in original ways, and integrate multiple disciplines to produce innovative solutions (Surmilasari et al., 2022).

The urgency of developing students' creativity has been widely recognized in various international education policies. Creativity is identified as one of the top ten essential skills for the future, alongside critical thinking and complex problem-solving (World

Economic Forum, 2020). Meanwhile, the Teaching, Learning and Assessing Creative and Critical Thinking Skills project emphasizes that creativity should be an integral part of school curricula, pedagogy, and assessment systems (OECD, 2023). These policies highlight that creativity is not merely a learning outcome but also a cognitive process that must be deliberately cultivated through collaborative, reflective, and contextual learning experiences.

In practice, classroom learning in schools often remains focused on rote memorization and final outcomes rather than on fostering students' creative processes. The level of creativity among students in Indonesian public schools is still relatively low, as teachers tend to adopt conventional, teacher-centered approaches (Rahmi et al., 2022). Consequently, students have limited opportunities to experiment, imagine, and independently generate new ideas.

The rapid transformation of society driven by technological advancement, digitalization, and global

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challenges has significantly reshaped the demands placed on education systems worldwide (Muchite, 2023). Schools are no longer expected to merely transmit knowledge, but rather to prepare learners who are capable of thinking creatively, solving complex problems, and adapting to uncertain and dynamic contexts (Zamana, 2022). In this regard, the development of students' creativity has become a strategic priority in education, as it underpins innovation, lifelong learning, and the ability to respond effectively to real-world problems. However, despite its recognized importance, creativity is still insufficiently nurtured through instructional practices that emphasize meaningful engagement, interdisciplinary integration, and deep learning processes. This condition highlights the urgent need for empirical research that explores effective learning models capable of systematically fostering students' creativity in formal classroom settings.

To address these challenges, a learning model that fosters deep and creative learning among students is essential. One relevant approach is Project-Based Learning (PjBL), as it positions students as active agents in designing, implementing, and evaluating projects related to real-world problems. Through PjBL, students are encouraged to think critically, collaborate effectively, and produce innovative work that reflects both conceptual understanding and divergent thinking skills (Susilawati et al., 2023).

The effectiveness of Project-Based Learning (PjBL) can be enhanced through integration with the STEM (Science, Technology, Engineering, and Mathematics) approach. This approach bridges theory and practice across disciplines, enabling students to recognize the interconnections between science, technology, and engineering in real-life contexts. The implementation of STEM-based PjBL not only improves cognitive learning outcomes but also fosters students' creative thinking and problem-solving skills (Muyassaroh et al., 2022).

On the other hand, teachers' roles as learning facilitators still face challenges in comprehensively understanding the indicators of creativity assessment, such as fluency, flexibility, originality, and elaboration. This limitation has resulted in the mentoring and evaluation processes of students' creativity not being fully optimized (Nasiruddin et al., 2023). The gap between the Project-Based Learning (PjBL) model and its classroom implementation indicates a research space that needs to be further explored—particularly regarding how PjBL can be effectively implemented within the framework of deep learning to genuinely foster the holistic development of high school students' creativity.

The integration of Project-Based Learning (PjBL) and STEM also supports the development of deep learning. Deep learning emphasizes students' active

engagement in constructing knowledge, connecting concepts with real-life experiences, and reflecting on their cognitive processes. When students engage in deep learning, they not only understand concepts but are also able to transfer and apply them in new contexts. This aligns with the findings of New Pedagogies for Deep Learning (NPDL, 2021), which assert that creativity flourishes when learning fosters conceptual understanding, application, and continuous reflection.

A growing body of research has confirmed the effectiveness of this approach. STEM Project-Based Learning has a significant impact on enhancing students' creativity across various educational levels (Kwon et al., 2025). In Indonesia, the implementation of PjBL-STEM has been shown to foster students' creative and collaborative thinking skills in science learning (Hindun et al., 2024). These findings indicate that a learning model integrating deep learning, PjBL, and STEM is highly relevant for development within the context of national education.

This study also proposes an integrative approach between Project-Based Learning (PjBL) and deep learning, which has thus far been rarely examined comprehensively in the context of Senior High School (SMA) education. The integration of these two approaches is believed to bridge the gap between conceptual understanding and the application of knowledge in real-world situations. Through projects designed based on the principles of deep learning, students do not merely act as recipients of information but as active creators of knowledge who explore, test, and construct ideas independently. In this context, the STEM approach serves as a key reinforcement, as it situates learning within authentic experiences that connect theory with the practical domains of science, technology, engineering, and mathematics.

Deep learning in the context of education refers to a learning process oriented toward conceptual understanding, critical reflection, and the ability to transfer knowledge to new and meaningful situations. Unlike surface learning, which emphasizes memorization and information reproduction, deep learning requires students' active engagement in constructing meaning, connecting ideas, and independently evaluating and applying concepts (Biggs et al., 2011; Fullan et al., 2018). This approach positions students as agents of learning who construct their understanding through authentic experiences, collaboration, and interdisciplinary exploration (OECD, 2023).

STEM-based Project-Based Learning (PjBL) is a learning model that focuses on the implementation of real-world projects by integrating four core disciplines, namely, Science, Technology, Engineering, and Mathematics. This approach aims to develop students'

critical, collaborative, and creative thinking skills through contextual problem-solving processes that reflect authentic real-life situations (Bybee, 2020; Sanders, 2009). In its implementation, students are engaged in the design, testing, and evaluation of projects that require the integrated application of scientific and technological principles, making the learning experience more meaningful and oriented toward deep learning. STEM-based PjBL emphasizes not only the final product but also the systematic thinking process that encourages students to integrate interdisciplinary concepts in producing innovative solutions (Muyassaroh et al., 2022).

Meanwhile, creativity is defined as the ability to generate new and original ideas that are useful in solving problems or creating something of value. In the educational context, creativity is not limited to artistic talent but refers to divergent thinking skills encompassing fluency, flexibility, originality, and elaboration (Doyan et al., 2023; Kaufman et al., 2021; Runco et al., 2012). This ability is crucial in the era of digital transformation and global complexity, where learners are required to adapt, innovate, and think critically in response to emerging challenges (OECD, 2023). In this regard, deep learning plays a vital role as it fosters reflection and deeper connections to acquired knowledge. When combined with STEM-based Project-Based Learning, students' creativity can be further enhanced through project activities that enable them to experiment, discover innovative solutions, and integrate multiple disciplines (Hanif et al., 2019; Widyawati, 2025).

Method

This study employed a descriptive qualitative case study design conducted at SMAN 1 Simpang Tiga over a one-month period. The research involved 30 eleventh-grade students, selected through purposive sampling based on teacher readiness and students' openness to innovative learning approaches. The study aimed to explore how the implementation of deep learning through an integrated STEM-based Project-Based Learning (PjBL) model enhances students' creativity. The research variables focused on the learning process and students' creative responses. Data were collected through classroom observations, in-depth interviews, and documentation during six instructional meetings, in which students worked collaboratively in small groups to complete projects designed jointly by the teacher and the researcher. The tools and materials used included learning modules, project guidelines, observation sheets, and interview protocols. Data trustworthiness was ensured through source triangulation by cross-

checking interview data with observation findings. Data analysis was conducted using qualitative descriptive techniques, including data reduction, data display, and conclusion drawing, to obtain a comprehensive understanding of the learning process and its impact on students' creativity.

Data in this study were collected using three primary techniques: participatory observation, semi-structured interviews, and document analysis. Observations were conducted directly during learning activities to identify and describe student behaviors that reflected various aspects of creativity. The creativity indicators observed included fluency (the ability to generate ideas), flexibility (the ability to think adaptively), originality (the uniqueness of ideas), and elaboration (the ability to develop and refine ideas).

Subsequently, semi-structured interviews were conducted with selected students and teachers as key informants to gain deeper insights into their learning experiences, responses, and perceptions regarding the implementation of STEM-integrated Project-Based Learning (PjBL) within a deep learning framework. This technique enabled the researcher to explore qualitative data that were reflective and contextual, capturing both the process and the impact of PjBL implementation. In addition, document analysis was performed by examining the students' project outputs. These products served as supplementary data to assess the level of creativity and the depth of conceptual understanding demonstrated by the students, as well as to corroborate findings obtained from observations and interviews.

The data analysis process was conducted using Miles and Huberman's interactive analysis model, which consists of three main stages: data reduction, data display, and conclusion drawing and verification. To ensure the validity and reliability of the data, the researcher applied source and method triangulation by comparing information obtained from observations, interviews, and documents. Additionally, member checking was conducted by involving teachers and students to verify the accuracy of the researcher's interpretations of the analysis results. Through this strategy, the study aimed to produce comprehensive, valid, and reflective findings regarding the effectiveness of Project-Based Learning (PjBL) within a deep learning framework in optimally developing students' creativity.

Result and Discussion

The following presents the results of observations and analyses of students' project outcomes in STEM-integrated Project-Based Learning (PjBL), as illustrated in Figure 1 below:

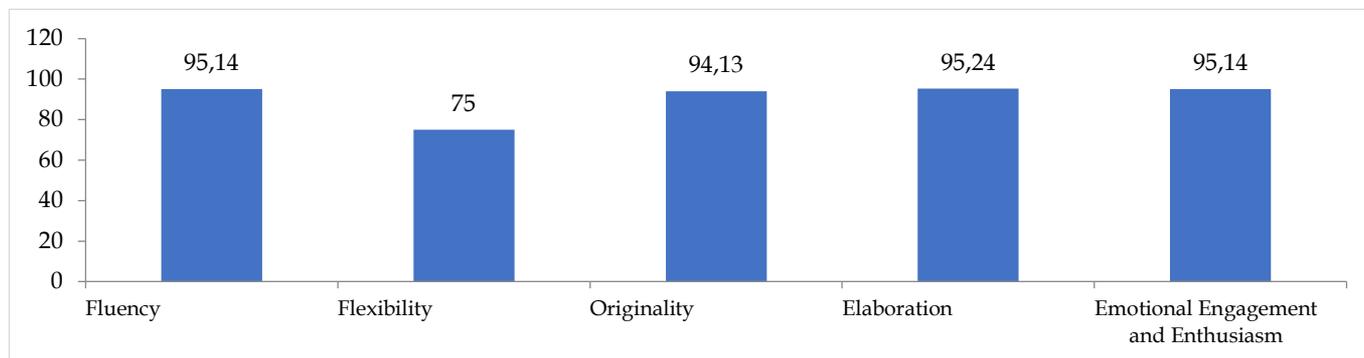


Figure 1. Observation results of creativity indicators

Based on Figure 1, the tabulated observation results of creativity indicators show the following: the fluency indicator had an average score of 95.14, categorized as very good. The flexibility indicator achieved an average score of 75, categorized as good. Meanwhile, the originality indicator obtained an average score of 94.13, also categorized as very good. The elaboration indicator fell into the very good category with a score of 95.24. Additionally, students’ emotional engagement and enthusiasm during the project-based learning process were classified as very good, with an average score of 95.14.

Fluency in STEM-Integrated Project-Based Learning

The results of the study indicate that the implementation of STEM-integrated Project-Based Learning (PjBL) significantly contributes to enhancing students’ idea fluency during the learning process. Based on observations over six sessions, it was evident that students were able to generate a greater number of ideas when faced with contextual problems that required creative solutions. At the initial stages of learning, most students tended to be passive and relied heavily on teacher guidance to express their ideas. However, after repeated engagement in STEM-based project activities, there was a marked improvement in both the quantity and diversity of ideas produced.

In addition, interviews with students revealed that the integration of STEM elements, particularly in the areas of technology and engineering, provided them with the opportunity to think openly and explore various possible solutions. The incorporation of science and mathematics concepts into the projects also helped students understand the connections between the disciplines involved in product design, thereby encouraging them to generate more logical and practical ideas. Teachers played a crucial role in facilitating idea fluency by providing trigger questions and feedback that promoted broader exploration of ideas.

These findings are consistent with previous research indicating that the implementation of STEM-integrated PjBL can significantly enhance students’

creative thinking skills, particularly in terms of idea fluency and cognitive flexibility (Nugraha et al., 2023). The integration of PjBL with the STEM approach effectively stimulates students’ idea fluency by providing opportunities for divergent thinking, experimentation, and modification of ideas within a collaborative and meaningful learning context. This reinforces the view that contextual and interdisciplinary project-based learning can enhance students’ creative capacities, especially in generating ideas that are fluent, diverse, and original.

Flexibility in STEM-Integrated Project-Based Learning

The results of the study indicate that the implementation of STEM-integrated Project-Based Learning (PjBL) effectively enhances students’ cognitive flexibility, which is closely linked to the development of Higher Order Thinking Skills (HOTS). Based on observations and interviews, students demonstrated adaptive thinking by modifying strategies, considering multiple alternative solutions, and integrating concepts from various disciplines to solve project problems. At the beginning of the learning process, students tended to think linearly and relied on a single solution. However, through STEM-based project activities, such as designing simple devices based on scientific and technological principles, students began to exhibit divergent and reflective thinking. For instance, they modified designs or combined mechanical and electronic principles to improve product effectiveness, as seen in the thermodynamics project of creating a simple cooling machine.

These results indicate that the integration of STEM within PjBL provides students with opportunities to develop cognitive flexibility, a crucial component of Higher Order Thinking Skills (HOTS) such as analysis, evaluation, and creation (Anderson et al., 2001). STEM-integrated PjBL encourages students to think across disciplines, remain open to changes, and adjust their thinking strategies according to the context of the problem (Djam’an et al., 2025). Consequently, PjBL-STEM not only enhances cognitive flexibility but also

strengthens students' higher-order thinking abilities in solving problems creatively and innovatively.

Originality in STEM-Integrated Project-Based Learning (PjBL)

Originality is a key dimension of creativity that becomes particularly evident during the implementation of STEM-integrated Project-Based Learning (PjBL). Observations indicate that students are able to generate ideas and products that do not merely replicate provided examples but reflect authentic and innovative personal thinking. Students demonstrate diverse approaches in designing content, selecting presentation media, and integrating local elements into their projects, resulting in outputs that are unique in terms of visual, narrative, and technical aspects.

Furthermore, the implementation of STEM-integrated Project-Based Learning (PjBL) creates a learning environment that fosters the emergence of original thinking in students. The trial-and-error process inherent in each stage of the project helps students perceive failure as a natural part of learning rather than something to avoid. They become accustomed to refining and improving their work without fear of negative evaluation. An open and non-judgmental learning environment serves as a crucial factor that encourages students to experiment and explore new ideas. This setting ultimately enhances students' confidence in expressing their creative ideas. This finding is further supported by evidence indicating that students engaged in project-based learning tend to generate more innovative ideas because they are given the freedom to think divergently and express their ideas without pressure (Rasmi, 2024).

Elaboration in Project-Based Learning (PjBL) Integrated with STEM

The aspect of elaboration is clearly visible during the implementation of STEM-integrated project-based learning, where students not only generate initial ideas but also develop and enrich those ideas into more detailed, practical, and meaningful forms. At each stage of the project, students undergo a refinement process through group discussions, consultations with the teacher, and trials of the designs they have created. This repeated process of revision and improvement demonstrates the students' ability to elaborate on ideas, both in terms of content, form, and function.

Observations show that the Project-Based Learning (PjBL) model provides a pedagogical framework conducive to the development of elaboration skills because it is cyclical, reflective, and iterative. Each project undertaken by students is not completed in a single stage but through a continuous development process involving social interaction, collaboration, and

the provision of formative and constructive feedback. Through this cycle, students have the opportunity to revisit their initial ideas, evaluate their shortcomings, and make improvements to better align with the goals and context of the project. These findings also indicate that allowing students space to revise based on feedback in PjBL encourages the enrichment of ideas and improves the quality of the final product (Hauko et al., 2025).

Emotional Involvement and Enthusiasm in STEM-Integrated Project-Based Learning (PjBL)

Observations during the implementation of project-based learning show that students experience a high level of emotional involvement at every stage of the activity. This is evident from the students' enthusiasm in completing tasks, their active participation in group discussions, and their positive expressions when presenting project results. Students demonstrate readiness and confidence to express their opinions without coercion from the teacher, indicating a sense of ownership toward the projects they work on. This kind of involvement reflects that learning occurs not only cognitively but also within the affective domain, where students feel motivated, challenged, and proud of their work.

Determination emphasizes that intrinsic motivation arises when individuals feel a sense of autonomy, competence, and social relatedness in the learning process (Deci et al., 2000). In this context, STEM-integrated PjBL provides students with the opportunity to choose, design, and carry out projects according to their interests and abilities, thereby fostering sustainable intrinsic motivation. Collaborative projects based on real-world challenges can enhance students' emotional involvement because they see a direct relevance between learning and the real world.

These findings are further supported by evidence that the implementation of STEM-based PjBL can increase students' enthusiasm and learning satisfaction through meaningful learning experiences (Wati, 2024). Thus, the emotional involvement and enthusiasm that arise during the learning process become important indicators of the success of STEM-integrated PjBL in creating an interactive, reflective learning environment that deeply fosters students' curiosity.

Implementation of Deep Learning with STEM-Integrated Project-Based Learning Model

Based on interview results, teachers perceive that the implementation of STEM-integrated Project-Based Learning (PjBL) with a deep learning approach has a positive impact on the quality of teaching and the development of students' thinking skills. Teachers assess that this model encourages students not merely to

memorize concepts but also to understand them deeply, connect concepts, and apply knowledge in real-world contexts. This approach is considered capable of fostering critical, creative, and reflective thinking skills because students are actively involved in designing, implementing, and evaluating projects oriented toward solving real-world problems.

Teachers also emphasize that the integration of STEM elements (Science, Technology, Engineering, and Mathematics) makes learning more relevant and contextual. Through activities such as experiments, product design, and data analysis, students learn to connect theory with practice and develop collaborative interdisciplinary skills. This process aligns with the characteristics of deep learning, where conceptual understanding is developed through meaningful exploration, critical reflection, and experiential learning. Nevertheless, teachers acknowledge certain implementation challenges, such as limited time, availability of STEM support facilities, and students' readiness for deep thinking and independent work. Teachers believe that the success of STEM-integrated PjBL with deep learning greatly depends on the teacher's role as a facilitator who can guide students through reflective questioning, provide formative feedback, and create a learning environment that encourages exploration and curiosity.

Deep learning in the context of PjBL enables students to build meaningful knowledge through hands-on experience, collaboration, and critical reflection. Furthermore, the integration of STEM in PjBL strengthens the connection between academic concepts and 21st-century skills, thereby creating a deep and transformative learning experience for students.

Teachers also assess that this learning approach creates a motivating learning environment and fosters student enthusiasm because they are given the freedom to express ideas and explore without fear of making mistakes. From an educator's perspective, this model is seen as effective in building a collaborative learning atmosphere and encouraging the fullest development of students' potential. This aligns with the findings of Lubis Lubis et al. (2022), which emphasize that in the implementation of PjBL, the teacher's role shifts from being the primary source of information to becoming a learning facilitator. Teachers provide opportunities for students to explore various sources of knowledge, collaborate in groups, and produce tangible products as a form of applying their understanding of the material studied.

Conclusion

The implementation of STEM-integrated Project-Based Learning (PjBL) within a deep learning

framework has been shown to effectively enhance students' creativity through collaborative, contextual, and exploratory learning processes. This approach improves key dimensions of creativity, including fluency, flexibility, originality, idea development, and students' emotional engagement, enabling learners to generate and transform ideas into meaningful products. The effectiveness of this model is closely linked to teachers' readiness to design relevant projects, provide appropriate guidance, and create supportive learning environments. Furthermore, this approach encourages a shift toward student-centered and reflective learning, positioning teachers as facilitators of creative and critical thinking. To strengthen empirical evidence, future research is recommended to employ quantitative or experimental designs supported by valid psychometric instruments.

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Author Contributions

Conceptualization: M.R. and I.I.; Methodology: M.R.; Validation and formal analysis: S.S. and M.M.; Investigation: M.M.; Resources provision: S.S.; Data curation: M.R.; Writing—original draft preparation: M.R.; Writing—review and editing: I.I.; Funding acquisition: I.I. and S.S.

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Conflicts of Interest

The authors declare no conflict of interest.

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