Proceedings of the 2nd International Conference on Islamic Education and Science Development (ICONSIDE)
Fakultas Tarbiyah dan Keguruan, Universitas Islam Negeri Mataram, Indonesia
Mataram, 11-12 June 2024 *Available online at* https://proceeding.uinmataram.ac.id/

Project-Based Learning to Improve Students' Creative Thinking Skills in the Field of Science

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ABSTRACT

Science is the discipline of investigating nature, its contents, and the events occurring within it. It holds significant value in human life because all human activities are intrinsically linked to nature. Creativity is a critical 21st-century skill. It plays a fundamental role in social life. It is defined as the ability to produce something novel, whether in the form of a product, process, or idea. Creativity is crucial for overcoming various limitations, solving problems in diverse areas of life, and generating innovative opportunities or solutions, particularly within education. Creative thinking, the cognitive process behind creativity, is directly related to an individual's creative capacity. The more proficient one is in creative thinking, the more creativity they will display. Involving students in designing their own experimental procedures enhances their scientific creativity. Project-based learning (PBL) demands students engage in experiments to solve problems and complete projects, making creativity an essential component of the process. This study definitively explores the advantages of project-based learning in fostering students' creative thinking skills.

KEYWORDS: project-based learning, science, creative thinking

INTRODUCTION

Science is the study of nature and everything in it, as well as the events that occur. Learning science is very important because all human activities are closely related to nature. Students' knowledge of science is related to the mastery of concepts and their application. Science learning is closely related to the study of natural phenomena to improve students' knowledge, skills, and attitudes. The studied science phenomena will have a deeper meaning if it is associated with the natural context in the surrounding environment. Therefore, an educator should guide students to not only textually understand what is written in the book, but also actively understand natural phenomena that are directly observed.

Understanding phenomena through contextual studies can increase students' awareness of dynamic environmental transformations, including ecological degradation, the adverse consequences of technological advancement, and climate change—factors that collectively influence ecological sustainability. This awareness underscores the urgent need to cultivate environmental literacy across all educational levels. Meanwhile, effective leadership demands originality in thought, enabling individuals to devise innovative solutions beyond conventional work constraints and to formulate comprehensive strategies or programs. Creativity is a critical asset for organizational resilience and competitiveness within saturated industries. Given that not all challenges can be resolved using routine approaches, the capacity for novel thinking becomes indispensable. Creativity significantly contributes to both societal development and individual progress, particularly within scientific inquiry, where it is considered a distinct and vital element. As noted by Zhu et al. (2019), creativity research spans interdisciplinary domains, with substantial contributions from diverse academic perspectives (Hernández-Torrano & Ibrayeva, 2020).

Creative thinking serves as the foundation of the creative process. Although creativity does not invariably culminate in the creation of tangible products, it does permeate myriad facets of life, encompassing abstract concepts. The crux of innovation lies in the generation of ideas that are genuinely original—ideas that have not been previously conceived. This cognitive approach entails the examination of problems from unconventional perspectives, a practice often termed "thinking outside the box." It is evident that even ostensibly mundane phenomena can be revitalized through the application of unique, transformative ideas. In educational settings, innovative learning materials have been shown to catalyze the emergence of innovation, productivity, and wisdom, thereby fostering both creative and transdisciplinary thinking (Chen & Chen, 2021). Fundamentally, human beings are inherently creative, continuously refining ideas in their everyday experiences. Creativity, therefore, is not solely defined by the introduction of novelty to the external world, but also by personal innovation and self-development. Changes initiated within the self frequently lead to broader transformations in the surrounding environment.

Encouraging students to design their own experimental procedures has been shown to enhance scientific innovation. Research indicates that students' scientific creativity varies significantly across grade levels. Specifically, third-grade students demonstrate lower performance in both convergent and divergent dimensions of scientific creativity compared to their peers in grades four through six, reflecting consistent developmental trends (Yang et al., 2016). Furthermore, students' implicit theories of creativity often link creative expression with scientific and artistic endeavors. Notably, gender-based differences also emerge, with boys exhibiting a higher tendency toward stereotypical perceptions—an outlook that may hinder alignment with pedagogical objectives (Potęga vel Zabik, Tanas, & Iłowiecka-Tanska, 2021).

The study revealed significant gender-based differences in divergent thinking abilities, with female students demonstrating superior performance in both divergent thinking and problem-solving tasks compared to their male counterparts within an experimental group participating in a science competition (Müller & Pietzner, 2020). The interaction between convergent thinking and divergent thinking components (fluency/flexibility) significantly influences scientific creativity. Notably, divergent thinking emerges as a predictor of creative performance only among individuals exhibiting high levels of convergent thinking. These results indicate a threshold effect of convergent thinking, wherein divergent thinking contributes to scientific creativity contingent upon attaining a requisite level of convergent thinking ability (Zhu et al., 2019).

The enhancement of scientific process skills plays a pivotal role in cultivating students' scientific creativity. However, the process of nurturing creativity is inherently complex, as multiple pedagogical strategies may contribute to its advancement in diverse ways (Dikici et al., 2018). The production of genuinely creative outcomes typically demands considerable time and reflects a high level of creative cognitive engagement (Forte-Celaya, 2021). To better understand the dynamics that sustain creative development, further empirical research is necessary—particularly to explore how various contributing factors interact and influence different levels of creative capability (Kupers et al., 2019).

The advancement of scientific process skills facilitates the enhancement of students' scientific creativity. Nevertheless, cultivating scientific creativity constitutes a multifaceted process wherein alternative pedagogical approaches may equally contribute to its development (Dikici et al., 2018). It takes time to develop creative products that result in high expression of creative thinking skills (Jacqueline Forte-Celaya, 2021). Further investigation is warranted to elucidate the interplay of multifactorial influences on sustained creative development, along with the operative mechanisms underlying their association with differential creative capacities (Kupers et al., 2019).

A significant relationship exists between pattern recognition and cognitive processes such as creativity and critical thinking, both of which are fundamental higher-order thinking skills in the 21st century. Although creativity shows a minor association with pattern recognition, the effect size is minimal and lacks substantial predictive power. In contrast, critical thinking exhibits a strong correlation with pattern recognition, marked by a large effect size and moderate-to-high predictive validity (Ling & Loh, 2020).

Creative thinking abilities can be nurtured through the integration of hands-on experiences within project-based learning (PBL) frameworks (Ahmad et al., 2021; Sumarni & Kadarwati, 2020; Yustina et al., 2020; Lou et al., 2017; Sari et al., 2017). Students generally perceive PBL as a powerful approach that enhances both creativity and learning capabilities (Lou et al., 2017). For instance, quantitative protein testing projects utilizing locally sourced materials have been shown to improve students' creative thinking, with an observed N-Gain score of 0.32. Learners report feeling more inventive during such practical sessions, particularly in selecting materials and designing procedural steps (Sari et al., 2017). Furthermore, the application of Blended Learning (BL) combined with PBL has been found to significantly enhance the creative thinking abilities of teacher candidates, outperforming traditional teaching models in effectiveness (Yustina et al., 2020). Ethno-STEM-oriented PBL also contributes to the improvement of students' critical and creative thinking across multiple indicators, although the measured outcomes typically range from low to moderate levels (Sumarni & Kadarwati, 2020).

Demographic variables have been shown to influence scientific creativity both directly and indirectly, with scientific process skills serving as a mediating factor. Although grade level is positively associated with the development of scientific process skills, it demonstrates a negative correlation with levels of scientific creativity—most notably, students in Grade 8 exhibit lower creative performance compared to those in Grades 7 and 9. Despite this, grade level and age were not identified as significant predictors of scientific creativity. Conversely, gender emerged as a significant factor, with female students outperforming their male counterparts in scientific creativity and process skills (Roth et al., 2021; Dikici et al., 2018). These findings suggest that gender differences in scientific creativity may be partially explained by disparities in scientific process proficiency. Furthermore, scientific process skills act not only as a mediator in the gender-creativity pathway but also as a moderator that influences the relationship between grade level, age, and scientific creativity (Dikici et al., 2018).

This research investigates the effectiveness of Project-Based Learning (PBL) in fostering creative thinking abilities among pre-service teachers. Considering the essential role of creative competencies in navigating complex educational demands and future societal challenges, the development of such skills in prospective educators is both necessary and urgent.

RESEARCH METHOD

This study employs a literature review methodology, utilizing scholarly articles from reputable journals as primary data sources. Through systematic analysis, elaboration, and synthesis of the selected literature, the research constructs a theoretical framework that informs preliminary recommendations prior to empirical field implementation.

RESULTS AND DISCUSSION

Project-based learning (PBL)

Project-Based Learning offers students authentic experiential learning opportunities, enabling them to consolidate their comprehension of theoretical principles. Empirical evidence demonstrates PBL's superior efficacy compared to conventional lecture-based instruction, establishing it as an optimal pedagogical approach for enhancing educational outcomes. Maximum instructional effectiveness is achieved when PBL integrates with direct instruction that introduces fundamental concepts, while extending learning through practical applications in laboratory or project contexts. Research confirms that PBL not only augments academic achievement but also significantly improves career readiness (Sababha et al., 2016).

As an inquiry-based pedagogical strategy, PBL facilitates the investigation of real-world problems. This approach fosters learner autonomy and collaborative engagement, thereby strengthening research competencies and problem-solving abilities. However, contemporary studies reveal implementation challenges for educators adopting student-centered methodologies in science education, necessitating greater instructor proficiency in PBL implementation (Bilgin et al., 2015).

PBL possesses transformative potential for science education by immersing learners in meaningful knowledge construction and impactful experiential learning. This methodology promotes the development of profound, transferable scientific understanding while cultivating collaborative problem-solving through innovative approaches to complex phenomena (Miller & Krajcik, 2019). PBL effectively connects theoretical knowledge with practical applications, with student feedback consistently affirming its benefits for conceptual mastery and real-world problem-solving capacity (Sababha et al., 2016).

Krajcik & Shin (2014) identify six defining PBL characteristics: 1) driving questions, 2) explicit learning goals, 3) scientific practices, 4) collaborative learning, 5) technology integration, and 6) artifact creation. The driving question serves as the project's conceptual anchor, ensuring thematic coherence. Effective PBL implementations should facilitate the acquisition of curriculum-aligned knowledge and skills through authentic scientific inquiry, comprising: topic orientation, hypothesis formulation, experimental investigation, data analysis, conclusion derivation, and results dissemination. This structured approach enhances both content mastery and communication skills (Lin et al., 2018).

Students engage in collaborative research, ideally incorporating partnerships with domain experts, industry stakeholders, or family members. Such collaborative engagements serve to enhance student motivation while fostering critical competencies in communication, task delegation, and role differentiation (Markula & Aksela, 2022). Technological integration in PBL facilitates learning through three primary mechanisms: stimulating interest, conceptual modeling, and strategic scaffolding. This integration has been shown to augment cognitive processing, support knowledge construction, and increase learner satisfaction during interdisciplinary project design (Hsu & Shiue, 2018; Shatunova et al., 2018). A defining characteristic of PBL is its focus on culminating artifacts that substantively address driving questions (Markula & Aksela, 2022).

Successful PBL implementation requires comprehensive design to ensure coherent science learning. Authentic engagement necessitates student involvement in developing, applying, and refining scientific concepts that address genuine needs within project contexts (Penuel et al., 2022). The PBL implementation framework proposed by Sababha et al. (2016) comprises seven sequential phases: (1) project conception and design, (2) detailed project planning, (3) proposal development including rationale, specifications, constraints, resource analysis, and task allocation, (4) periodic progress reporting, (5) final digital submission, (6) multimedia dissemination including video posters, and (7) final presentation with prototype demonstration. Assessment incorporates multiple dimensions: presentation quality, collaborative dynamics, design efficacy, conceptual understanding, and problem-solving capacity, supplemented by peer evaluation mechanisms (Sababha et al., 2016).

Chao et al. (2017) conceptualize PBL as a five-stage pedagogical process: (1) student-directed thematic exploration, (2) co-constructed learning environments, (3) principle derivation through conceptual engagement, (4) cognitive tool utilization with iterative presentation, and (5) collaborative capacity development through sustained learning initiatives.

Empirical evidence indicates significant positive correlations between instructional quality, social dynamics, and cognitive engagement (Hsu & Shiue, 2018). The development of transferable knowledge - defined as the capacity to apply conceptual understanding to problem-solving and phenomenon explanation - can be enhanced through curricular designs emphasizing conceptual coherence, depth of understanding, and intrinsic motivation. Current research initiatives focus on synthesizing these approaches through iterative curriculum development spanning four academic years (Miller & Krajcik, 2019).

As an inquiry-based pedagogical strategy, PBL promotes learner autonomy while developing essential research and problem-solving competencies (Bilgin et al., 2015). Notably, pre-service teacher engagement in PBL practicums correlates strongly with positive affective experiences and enhanced pedagogical preparedness for implementing PBL methodologies (Tsybulsky & Muchnik-Rozanov, 2021).

Creative Thinking Skills

Guilford (1950) identified divergent thinking as a fundamental element of creativity, framing it as a cognitive skill that can be assessed through standardized paper-based instruments across different settings. Expanding on this notion, Guilford (1967) developed a three-dimensional model of intelligence, in which divergent thinking is characterized by three principal attributes: (a) fluency, or the ability to generate a high volume of ideas; (b) flexibility, referring to the production of ideas across varied conceptual domains; and (c) originality, the capacity to produce uncommon or novel responses. This conceptualization positions creativity as a quantifiable mental process, distinct from traditional problem-solving by its emphasis on the diversity and uniqueness of thought.

Creativity is characterized by several key dimensions. First, fluency refers to the capacity to produce a large number of ideas within a short period. Second, flexibility denotes the ability to generate diverse responses or perspectives, approach problems from multiple angles, explore alternative solutions, and apply varied cognitive strategies. Third, elaboration involves the skill to expand upon ideas by adding intricate details and developing concepts, objects, or scenarios with depth and precision.

Guilford delineated several key indicators of creative thinking: (a) Problem sensitivity, referring to an individual's capacity to identify, interpret, and respond to challenges or contextual issues; (b) Fluency, the ability to produce a high volume of ideas; (c) Flexibility, denoting the generation of diverse and alternative approaches to resolving problems; (d) Originality, which involves producing novel, uncommon, and non-stereotypical ideas; and (e) Elaboration, the skill to expand on a concept or problem with detailed elements, which may include visual aids, such as charts, diagrams, or models, as well as descriptive explanations.

Complementing this, William emphasizes that mathematical creative thinking encompasses four central dimensions: fluency, flexibility, originality, and elaboration. Furthermore, creative thinking is characterized by three critical criteria: it must (1) yield responses that are original or statistically infrequent, (2) offer viable and contextually appropriate solutions, and (3) retain the core essence of initial ideas while refining and expanding them. Ultimately, genuine creativity is rooted in personal cognitive processes, rather than the reproduction of others' work.

The integration of creativity into the science education process is imperative for facilitating the comprehension of complex scientific concepts. Creativity has been demonstrated to be a catalyst for cognitive development in both structured and informal settings. Despite the absence of a universally accepted definition or standardized assessment of creativity, its role in development is unquestionable. However, the effective integration of creativity in curricula is contingent on numerous variables. Educators frequently encounter difficulties in cultivating and evaluating creativity, largely due to an inadequate grasp of the underlying factors. Therefore, the utilization of a reliable instrument for the evaluation of creativity is imperative for educators to identify, acknowledge, and comprehend its determinants within the limitations imposed by science instruction (Roth et al., 2021)..

The enhancement of scientific creativity can be facilitated through the cultivation of scientific process skills. The development of these skills is facilitated by project-based activities incorporated into instructional methodologies, a concept that is often referred to as project-based learning. Nevertheless, cultivating scientific creativity is a multifaceted endeavor. (Dikici et al., 2018).

Creativity holds a vital and actionable role in enriching students' experiences within science education. To harness its full potential, educators require a structured pedagogical framework that supports the transformation of students' original ideas into meaningful, observable products. This framework should encompass deliberate efforts to explore students' thought processes, guide them in recognizing task-related constraints, and facilitate ample opportunities for cognitive exploration and experimentation. Open-ended tasks—such as those found in engineering design and inquiry-based learning—create optimal conditions for fostering creativity, as they allow learners to engage in inventive thinking and produce concrete manifestations of their ideas. Despite the inherent challenges these tasks present, the application of purposeful questioning strategies has been shown to significantly enhance students' problem-solving capabilities (Shin et al., 2021; Stieff et al., 2020).

Creativity is a multifaceted phenomenon involving various patterns and elements. Scientific creativity is the process of applying scientific knowledge to generate original, innovative, and scientifically valid products. Creativity is the integration of knowledge from different disciplines to produce a final product. It is clear that this process is shaped by students' personal values, beliefs, and social contexts. It is clear that creativity is influenced by socio-cultural factors, ethnographic traits, and socially shaped personal perspectives (Smyrnaiou et al., 2020). Kang (2020) definitively shows that children's critical thinking, their perception of a creative classroom environment, and their creative tendencies are linked. Creativity originates not only within the brain but also in collaborative thinking within socio-cultural settings. Children's creativity flourishes in cooperative settings where intrinsic motivation and curiosity drive them to exchange ideas while solving problems collectively.

Spatial thinking has been increasingly recognized as a critical factor influencing student achievement in Science, Technology, Engineering, and Mathematics (STEM). Recent investigations have focused on how spatial training interventions impact mathematics learning among elementary students. Research by Burte et al. (2020) highlights a correlation between educators' beliefs and attitudes toward mathematics and their perceptions of spatial cognition. Despite the central role spatial abilities play, findings suggest that even foundational perceptual processes can be strategically harnessed to support success in STEM education. Conventional curricular frameworks often prioritize semantic content organized within subject-specific constructs; however, they provide limited opportunities for students to engage with these constructs through multiple representational forms (Stieff et al., 2020).

Although scholarly attention to the significance of spatial reasoning in science education is growing, its deliberate integration into instructional practices remains uncommon (Gagnier & Fisher, 2020). In response, Shin et al. (2021) proposed a Project-Based Learning (PBL) model that incorporates technological, curricular, and pedagogical components aimed at fostering computational thinking through student modeling activities. Furthermore, Kijima et al. (2021) reported that adolescent girls participating in STEM-oriented workshops experienced enhanced interest, improved self-efficacy, more favorable attitudes toward STEM, increased empathy and prosocial behavior, and broadened career aspirations. These findings underscore the transformative potential of brief, targeted interventions in shaping young women's perceptions and aspirations in STEM fields. In contexts shaped by gender norms, innovative approaches such as design thinking may play a vital role in revitalizing curricula—empowering girls to cultivate confidence, creativity, and a clearer vision for their futures in STEM careers.

CONCLUSIONS

Project-Based Learning (PBL) is widely recognized as one of the most effective pedagogical strategies for fostering 21st-century competencies within progressive K–12 science education. As a student-centered and problem-driven approach, PBL is structured around the development and execution of a project. The process typically involves several sequential stages: initiating and formulating the project concept, developing a formal project proposal, compiling regular progress reports, conducting an evaluation phase, and culminating with a project presentation. Core elements that define PBL include the use of driving questions, the articulation of explicit learning objectives, engagement in scientific practices aligned with the scientific method, collaborative teamwork, the integration of digital tools, and the creation of tangible products or artifacts. Within this framework, creative thinking is operationalized through four key indicators: fluency (the generation of numerous ideas), flexibility (the ability to approach problems from various perspectives), originality (the capacity to produce novel and uncommon ideas), and elaboration (the refinement and expansion of those ideas into detailed outcomes).

ACKNOWLEDGMENTS

We would like to thank the proceedings committee for publishing this article. Our gratitude also goes to all parties for the support and opportunities given to conduct research and publish the results of this study.

AUTHOR'S CONTRIBUTION

RS, AR, S and AAS provided the idea to conduct the research, made the research design and collected the data, RS analyzed the data and wrote the discussion and conclusion.

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