JPPIPA 9(11) (2023)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Project-Based Learning Supports Students' Creative Thinking in Science Education

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Received: August 21, 2023
Revised: October 14, 2023
Accepted: November 25, 2023
Published: November 30, 2023

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DOI: 10.29303/jppipa.v9i11.5054

Abstract: Creativity is recognized as a crucial 21st-century skill. Creativity plays a significant role in societal life, bringing forth something that did not exist before, whether it be in the form of products, processes, or ideas. Creativity is vital for navigating the limitations we encounter, solving problems across various aspects of life, and generating new opportunities or works to address a range of issues, including in the realm of education. Creative thinking is the process that yields creativity. The better someone is at creative thinking, the more creative they are as individuals. In other words, that person possesses high creativity. Involving students in designing their own experimental procedures will encourage their scientific creativity. Project-based learning requires students to conduct experiments to solve problems and complete given projects. Creative thinking from students is essential in these project endeavors. Hence, in this article, the researchers attempt to unearth the advantages inherent in project-based learning for bolstering students' creative thinking skills in science education.

Keywords: Creative thinking; Project-based learning; Science education

Introduction

A leader is expected to possess creativity in thinking to find solutions within work constraints and to develop various plans or work programs. Creativity can enable an organization to endure and stand strong amidst competitors in the same industry. Not all work-related challenges can be resolved using the same approach. Therefore, it is crucial for an individual to have creativity. Creativity plays a pivotal role in both society and individual development, and within the domain of science, it takes on a specific form (Zhu et al., 2019). Research on creativity and education is interdisciplinary in nature and integrates advancements produced by scholars from various disciplines and perspectives. (Hernández-Torrano & Ibrayeva, 2020).

James C. Coleman and Constance L. Hammen argue that creativity is "Thinking which produces new methods, new concepts, new understanding, new inventions, new works of art." Creativity involves bringing forth something that did not exist before, whether it be in the form of products, processes, or ideas. Creativity is crucial for navigating the limitations we encounter, solving problems across various aspects of life, and generating new opportunities or works to facilitate our lives and work.

Creative thinking is a thought process that generates creativity. Creativity doesn't always result in concrete products; it encompasses all aspects of life, including ideas. The essence of a creative idea is that no one has thought of it before. Creative idea's view something not from the usual perspective, but from a different angle. This is known as thinking "outside the box." No matter how mundane the appearance of something is, there's always an opportunity to make it better with a creative and impactful idea.

Innovative educational content will give rise to dimensions of innovation, production, and wisdom that enable innovative presentation in creative thinking and cross-boundary thinking (Chen & Chen, 2021). In reality,

How to Cite:
Sucilestari, R., Ramdani, A., Sukarso, A., Susilawati, S., & Rokhmat, J. (2023). Project-Based Learning Supports Students' Creative Thinking in Science Education. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 1038–1044. https://doi.org/10.29303/jppipa.v9i11.5054

humans are creative beings because we consistently modify existing ideas in our everyday lives. Creativity doesn't necessarily mean developing something new for the world; it's even more important to initiate and develop something new for ourselves first. When we change ourselves, the environment follows suit.

Involving students in designing their own experimental procedures will encourage their scientific creativity. Overall, the scientific creativity of students significantly differs across the three grade levels. The scientific creativity performance of third-grade students is significantly lower than that of the other grades (fourth to sixth grade elementary school), both in terms of divergent creativity and convergent creativity aspects. Both types of creativity follow the same changing pattern based on grade levels (Yang et al., 2016). The theory of implicit creativity associates creative efforts with the work of artists, and even scientists. The level of stereotypical thinking is higher in boys than in girls, and it inversely correlates with the students' learning objectives (Potęga vel Żabik et al., 2021).

Gender differences influence divergent thinking ability; female children within the student group perform better in divergent thinking and problem-solving than both female and male children within the experimental group participating in science competitions (Müller & Pietzner, 2020). Convergent thinking interacts with the fluency or flexibility of divergent thinking in scientific creativity. Specifically, divergent thinking predicts creativity in those with high levels of convergent thinking. Findings indicate a threshold-setting effect of convergent thinking, meaning that only when the capacity for convergent thinking reaches a certain level can divergent thinking play a role in scientific creativity (Zhu et al., 2019).

Enhancing scientific process skills will elevate students' scientific creativity, but developing scientific creativity is an exceedingly intricate process (Dikici et al., 2018). Time is required in developing creative products to yield expressions of high-level creative thinking skills (Celaya et al., 2021). Further research is needed to elucidate the interaction of various factors that can foster long-term creativity and the mechanisms that can connect them at different levels of creativity (Kupers et al., 2019). There is a significant relationship between creativity and pattern recognition (Ling & Loh, 2020).

Creative thinking abilities can be enhanced by providing hands-on experiences through project-based work processes (Ahmad et al., 2021; Lou et al., 2017; Sari et al., 2017; Sumarni & Kadarwati, 2020; Yustina et al., 2020). The majority of students agree that project-based learning can enhance their creativity and learning abilities (Lou et al., 2017). Quantitative project-based protein testing can enhance students' creative thinking abilities with an N-Gain of 0.32. This improvement is evident, for instance, in their ability to select materials and laboratory procedures (Sari et al., 2017). Project-Based Learning has an impact on enhancing the creative thinking abilities of prospective teachers (Yustina et al., 2020). The implementation of project-based learning is capable of increasing the average creative thinking abilities of students across all indicators, yielding results that range from low to moderate levels (Sumarni & Kadarwati, 2020). There is a significant gender effect on scientific creativity, where it is predominantly dominated by female students (Dikici et al., 2018; Roth et al., 2021). The scientific process skills of female students are higher than those of their male counterparts. However, further study and analysis are needed to identify the underlying reasons for this difference (Dikici et al., 2018).

In this article, the author attempts to explore the advantages of project-based learning in supporting the creative thinking of prospective teacher students. Creative thinking skills among prospective teacher students are of paramount importance for addressing various challenges in the realm of education and their future lives.

Method

The research method employed is a literature review using a literature study approach. The data sources utilized consist of reputable scholarly articles relevant to the discussed topic. The results of this literature review are analyzed, elaborated upon, and synthesized to construct a theory, which serves as one of the recommendations before directly engaging in fieldwork.

The brief stages of literature search include analyzing the research problem, determining keywords relevant to the research problem, selecting primary literature indexed in Scopus, choosing terms appropriate to the field of study, conducting the search, refining the selection based on search results, and identifying references for use as source material, as presented in Figure 1.

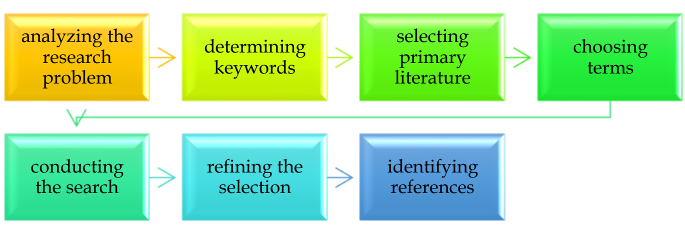

Figure 1. Stages of Literature Search

Result and Discussion

Project-based learning

Project-Based Learning (PjBL) provides students with direct real-world experiences to enrich their understanding of theoretical and technical concepts. Proven to be more effective than traditional teaching and learning methods, PjBL has become an ideal approach for enhancing student education. PjBL is most effective when combined with face-to-face instruction that introduces students to theories and concepts. PjBL takes this learning further by applying it to hands-on applications such as laboratory work or assigned projects during the learning process. Literature shows that PjBL not only enhances student learning but also better prepares them for future careers (Sababha et al., 2016).

PjBL is utilized as a research-based investigative strategy to find solutions to everyday life problems. In this approach, students take responsibility for their own learning and collaborate with others, enhancing their investigative and problem-solving skills. In recent years, research has shown that teachers face challenges in implementing student-centered learning approaches. Hence, teachers need to gain more experience in how to effectively use project-based learning strategies to teach science (Bilgin et al., 2015).

PjBL has the potential to reshape science education by involving students in meaningful and constructively building experiences. PjBL supports students in developing deeper and more relevant scientific knowledge. Students are also engaged in collaboration and discourse to understand phenomena or problems in creative ways (Miller & Krajcik, 2019). Project-based learning is believed to bridge the gap between theoretical education and the real world. Feedback from students confirms the effectiveness of PjBL in enhancing students' understanding and their ability to apply concepts to solve real-world problems. (Sababha et al., 2016). There are six main characteristics of PjBL according to Miller and Krajcik (2019); Shin et al. (2021) as presented in Table 1.

The application of project-based learning requires us to explore how to support coherent science learning from the student's perspective. Engaging students in practices as they build, use, and refine scientific ideas means creating a genuine need for science projects (Penuel et al., 2022).

Table 1. Characteristics of Project-Based Learning

Main Characteristics	Explanation
Prompting Questions	One of the most commonly recognized characteristics of PjBL is the presence of driving questions that serve as the project's focal point. Driving questions create continuity and cohesion.
Learning Objectives	PjBL should enable students to learn new topics and core curriculum skills.
Scientific Practices	Students should actively employ scientific methods to address and explore driving questions, which include: topic orientation, conceptualization involving formulating research questions and presenting hypotheses, investigation, conclusion, and discussion: communicating results and reflection (Lin et al., 2021)
Collaboration	Students conduct research by collaborating with each other. Ideally, this involves collaboration with experts, companies, or parents. Collaborative activities can motivate students and allow them to develop their communication skills, practice sharing responsibilities, and assuming roles (Markula & Aksela, 2022)
Using Technological Tools	Technology can support student learning through, for example, enhancing interest, concept modeling, and strategic support. Technology in PjBL enhances learners' cognition and learning, aids learners in developing knowledge management processes, and enhances their satisfaction while collaborating in designing interdisciplinary projects (Hsu & Shiue, 2018; Shatunova et al., 2018)
Creating artifacts or products	In PjBL, the learning process is centered around producing artifacts or final products that address the driving questions (Markula & Aksela, 2022)

The steps of project-based learning according Sababha et al. (2016) namely students are required to design and develop a project; students create the design of the project to be developed; students are asked to create a project proposal comprising the background, explanation of the idea or project, design conditions and limitations, all components to be used and their benefits, cost analysis, activity plan, and task allocation presented in table form; if the proposed proposal meets the criteria, it is approved and the project will proceed. Students are required to periodically submit progress reports. This is intended to ensure that everyone is on the right track; before project evaluation at the end of the semester, students are required to submit online reports. The report includes an Abstract, Introduction and Background, Design (Mechanical, Electrical, and Embedded Software), Results, Problems and Recommendations, and Conclusion; in addition to the report, students are also asked to create a poster about their project and upload their project to YouTube; the final stage is the presentation. Students present the poster they created and demonstrate their prototype. Assessors will evaluate students' presentation skills, teamwork, project design, their understanding of the project created, and students' problem-solving skills. Peer evaluation is also conducted, where each team member assesses other team members from their perspective (Sababha et al., 2016).

Meanwhile, according to Lou et al. (2017) the stages of PjBL teaching are summarized into five stages: student-centered and providing students the opportunity to explore themes; students and teachers co-create a learning environment and design problems for exploration; encouraging students to think and construct principles from the concepts of learning activities; guiding students to use cognitive tools and present their work progressively; and reinforcing the stage of learning initiative to help students develop their collaborative skills.

The research findings indicate that students' cognitive presence is positively influenced by both instructional and social presence (Hsu & Shiue, 2018). Usable knowledge is the ability to use ideas to solve problems and explain phenomena. We offer a process for designing a curriculum system that enhances how students learn science as a progression towards the advanced practice of usable knowledge, focusing on coherence, depth, and motivation. We see the potential of these different approaches to inform each other, and we anticipate a 4-year research involving iterative processes in our curriculum design to integrate the two best approaches to support student learning (Miller & Krajcik, 2019).

PjBL is utilized as a research-based investigative strategy to discover solutions to everyday life problems. In this approach, students take responsibility for their own learning and collaborate with others, enhancing their investigative and problem-solving skills (Bilgin et al., 2015). Students' experiences in PjBL-based practicum develop the pedagogical competencies they possess (Tsybulsky & Muchnik-Rozanov, 2021). Shin et al. (2021) introduced project-based learning (PjBL) features to develop technological, curricular, and pedagogical support for engaging students in computational thinking (CT) through modeling.

Creative Thinking

Creativity is an essential component of higher-order thinking skills within the context of 21st-century skills (Ramdani et al., 2021; A. Sukarso et al., 2019). The success of a student becoming a teacher with excellent science teaching capabilities needs to be supported by creative thinking skills, as creative thinking generates new ideas that contribute to the improvement of learning quality (Ramdani & Artayasa, 2020). Creativity is crucial for formulating new questions, deductive and inductive reasoning, and integrating unrelated knowledge through creative thinking. Therefore, the education system should prioritize the development of creativity (A. A. Sukarso & Muslihatun, 2021).

Guilford (1950) introduced divergent thinking as a key property of creativity, measured as intellectual ability in various contexts and situations beyond traditional paper-and-pencil tests. The three-dimensional structure of Guilford's intellect model (1967) measures fluency, the ability to generate a large number of ideas; flexibility, the ability to generate ideas in different categories; and originality, the ability to produce unusual and unique ideas.

Characteristics of creativity include: fluency of thinking, which is the ability to rapidly produce a multitude of ideas; flexibility, which involves producing varied ideas, answers, or questions, seeing problems from different perspectives, seeking diverse alternatives or directions, and employing various approaches or ways of thinking; elaboration, which entails the ability to develop and expand upon ideas, objects, or situations.

According to Guilford, indicators of creative thinking are: problem sensitivity, the ability to detect (recognize and understand) and respond to statements, situations, and problems; fluency, the ability to generate numerous ideas; flexibility, the ability to propose various solutions or approaches to problems; originality, the ability to generate ideas in ways that are novel, non-stereotypical, and rarely given by most people; elaboration, the ability to enhance situations or problems to make them complete, detailed, and comprehensive, including elements like tables, graphs, images, models, and words.

According to William, creative thinking is a mathematical ability that encompasses four key skills: Fluency, Flexibility, Originality, and Elaboration. There are three conditions that need to be met for creative thinking. First, creativity involves new responses or ideas that are statistically rare. Second, creativity should realistically solve problems. Third, creativity involves an effort to preserve original insight, evaluating and developing it as effectively as possible. In other words, the thinking should originate purely from one's own knowledge and understanding, not copied or imitated, not plagiarizing someone else's work or ideas.

Integrating creativity into science classrooms can pave the way to leverage complex scientific phenomena. Although not definitively defined or assessed using standardized measures, creativity is understood to support cognitive learning in formal and informal settings. However, the success of integrating creativity into educational modules depends on many factors. Since our knowledge of identifying these factors is limited, teachers may struggle to monitor and develop creativity effectively. As a result, valid means of measuring creativity will aid teachers in identifying creativity and its influencing factors within the limited scope of science lessons (Roth et al., 2021). Scientific creativity can be enhanced through scientific process skills. These skills are trained when learners are provided with a project-based learning process. However, developing scientific creativity is a highly complex process (Dikici et al., 2018).

Creativity can and should play a role in students' science experiences. A framework is needed for teachers to assist students in transforming their creative ideas into creative products. This framework involves taking the time to listen to students' ideas, helping them identify task constraints, and giving them ample opportunities to think about and experiment with their ideas. Unstructured problems, as found in inquiry and engineering design activities, provide excellent opportunities for students to engage in creative processing and express their creativity through the creation of products. These types of problems are typically challenging, but the use of appropriate questioning has been proven to aid students in problem-solving (Shin et al., 2021; Stieff et al., 2020).

Creativity is a complex and diverse phenomenon, encompassing creativity patterns and its components. Scientific creativity involves a procedure where all institutions, especially students, use their scientific knowledge to produce original, authentic, creative, imaginative, scientific, and acceptable products. Creativity requires knowledge transformation; hence, it is a procedure that combines scientific principles from different subject domains and scientific fields that collaborate to produce products at the end of learning. The transformation procedure is influenced by students' personal values, beliefs, and social environments. Therefore, the creative process is influenced by socio-cultural factors, ethnographic characteristics, personal beliefs, and ideas, which are socially constructed (Smyrnaiou et al., 2020).

Kang (2020) states that there is a correlation between children's critical thinking, children's perception of a creative classroom climate, and children's creative disposition. Creativity does not only reside within our brain system but emerges from interaction with people's thoughts in a socio-cultural context. Children's creativity can be nurtured through cooperative processes where children are motivated by their own interests and curiosity and are free to share their opinions with others to solve problems collectively. Additionally, considering how spatial thinking is linked to outcomes in Science, Technology, Engineering, and Mathematics (STEM (Burte et al., 2020). The importance of spatial thinking in science has gained increased attention in academic discussions; however, intentional spatial thinking teaching practices are still largely absent from curricula (Gagnier & Fisher, 2020).

Conclusion

Project-Based Learning (PjBL) can be a useful approach to promote 21st-century learning and skills in future-oriented K-12 science education. PjBL refers to problem-oriented and student-centered learning organized around projects. The steps of project-based learning are designing and developing the project, creating a project proposal, providing periodic reports, project evaluation, and presentation. There are six main characteristics of PjBL: the presence of driving questions, learning objectives, scientific practices through scientific method steps, collaboration, technology use, and artifact or product creation. Indicators of creative thinking include sensitivity to problems, fluency, flexibility, originality, and elaboration.

Acknowledgments
Thanks to All Lecturers and staff of the Postgraduate Science Education Doctoral Program at the University of Mataram for their guidance and direction

Author Contributions
The author is involved in the overall making of this article.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

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