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Enhancing mathematical problem-solving ability through project-based learning: A study of vocational high school student

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Abstract

This study aims to improve the mathematical problem-solving ability of students at Vocational High School (VHS) through implementing Project Based Learning (PjBL). The research method used was a quasi-experiment with a matching-only pretest-posttest control group design, with a sample of 64 students divided into two classes, namely experimental and control classes, each consisting of 32 students. The sampling technique used was purposive sampling, where the sample was selected based on specific criteria relevant to the research objectives. Data were collected using tests of mathematical problem-solving ability administered before (pre-test) and after (post-test) the treatment. Data were analyzed using an independent sample t-test and a two-way ANOVA test with univariate general linear model (GLM) analysis. The results showed a difference between the experimental and control groups before the treatment. However, after the treatment, the experimental group had higher mathematical problem-solving ability than the control group, including the improvement and interaction between PjBL implementation and the Early Mathematics Skills (EMS) category.

Keywords: geometry learning; mathematics learning; project-based learning; problem-solving; vocational high school

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Introduction

Vocational High Schools (VHS) play an important role in Indonesia's economic progress, turning the country into a new economic power (Kurniawan & Managi, 2018). They influenced the number of jobs available, and VHS was here to give them an individual learning experience (Barak & Shoshana, 2020). Therefore, VHS students must be taught specific conceptual, procedural, and dispositional information about their field of study (Billett, 2013). However, VHS Stakeholders find it challenging to identify an appropriate learning paradigm (Placklé et al., 2020). Many alternative teaching approaches seek to integrate mathematics and vocational learning. One of them is the math teacher, and VHS collaborated on a project that can be done inside or outside the math class (Dalby & Noyes, 2015). Mathematics and its concepts are found in all processes and diverse relations in many engineering fields, both in the theoretical constructs applied to description and in the phenomenological representations and physical spatial arrangements in which these professionals work (Santos et al., 2020).

For this reason, a change in how mathematics is taught at vocational schools is necessary to better prepare students for the workforce (Frejd & Muhrman, 2020). PjBL is predicted to be a viable alternative to contemporary learning in VHS. Teachers must contextualize mathematics in real-world situations to make mathematics learning relevant (Dias, 2015). PjBL has been applied in the medical, engineering, educational, economics, and business fields for years (Capraro & Slough, 2013). The PjBL process aims to continue narrowing the gap between the skills developed and those required by the community (Lima et al., 2017). PjBL allows students to learn by doing and apply concepts in real-world actions comparable to those practiced by professionals (Krajcik & Blumenfeld, 2006; Petrosino, 2004).

PjBL is student-centered, with a constructivist learning process (Kokotsaki et al., 2016), thereby encouraging students to work independently through collecting authentic products, opening up opportunities for students to become accustomed to investigating, asking questions, and solving real-world problems (Setyarini et al., 2020). Students are responsible for constructing their knowledge through constructivist methods (Pinho-Lopes & Macedo, 2016; Tsybulsky et al., 2020). Constructive activity is when knowledge is interpreted, regulated, and adapted to new conditions (Vye et al., 1997). This technique makes learning more relevant to students' lives (Greenier, 2020), especially in developing scientific process skills, which can be carried out through individual or group-assigned project work investigating information on a particular topic (Kzkapan & Bektaş, 2017). PjBL is used well when students have a deep conceptual understanding but can damage students with shallow knowledge (Holmes & Hwang, 2016).

Previous research on PjBL has shown positive effects on student's cognitive abilities, including influencing student achievement in mathematics (Branch, 2015), demonstrating critical thinking skills and intrinsic motivation that are higher than traditional learning (Holmes & Adams, 2006), and it can reduce the learning achievement gap because its implementation is more profitable for low achieving students (Han et al., 2016). On the other hand, the results of these studies contradict other studies, which state that although PjBL with ambitious pedagogical techniques is effective in several classes, it does not positively affect students' attitudes toward mathematics (Sonnert et al., 2015). So, research on PjBL can be carried out through further studies on the implementation of PjBL in the learning process, improving the quality of measuring instruments, and improving the quality of data analysis (Guo et al., 2020).

The primary goal of this study is to determine whether PjBL can help Indonesian VHS become more proficient at mathematical problem-solving. The implementation of PjBL follows five main steps: project theme selection, learning context determination, project planning, project execution, and project completion (Santyasa et al., 2020). This study will examine differences in students' mathematical problem-solving abilities due to PjBL implementation. PjBL is an ideal learning paradigm for increasing the productive abilities of VHS students (Fajra & Novalinda, 2020), significantly increasing motivation and facilitating increased problem-solving skills, thereby increasing students' cognitive and affective capacities (Chiang & Lee, 2016a). However, the fact is that mathematics is not a component of productive competence in VHS, so it is necessary to examine whether PjBL has a positive effect on the mathematical competence of VHS students, especially in their ability to solve mathematical problems. Students who have mastered mathematics demonstrate problem-solving, mathematical reasoning, procedural fluency, and conceptual knowledge (Niss, 2003).

Problem-solving theory and practice show that thinking is more important than knowledge in solving problems (Carson, 2007), so it occupies a key place in mathematics instruction and can be classified as a higher-order thinking talent (Sari et al., 2019). Problem-solving can be defined as the process of prior knowledge obtained for new and unexpected situations (Pehkonen, 1993). Solving math problems can help students improve their analytical skills and apply them in various situations (Sari et al., 2019). The problem is the discrepancy between the existing and intended state; problem-solving reduces this difference (C.-S. Tan et al., 2019). The issues may be authentic to professional work or related to the concepts and procedures comprising a disciplinary knowledge body (Branch, 2015; Frey et al., 2022; King & Smith, 2020; MacLeod & van der Veen, 2020). In addition, most of the problems raised cannot be resolved instantly, are open-ended, sometimes cannot be resolved, and require investigation (Bishara, 2016; Özcan, 2016).

Complex math problems require a solid foundation for students (Gill et al., 2010). Students who need more basic mathematical understanding can perform accurate algebraic and numerical calculations ((Fitzmaurice et al., 2019). The essence of mathematics is the ability to solve problems (Phumeechanya & Wannapiroon, 2014); students' skills will improve if they participate in problem-solving and successfully find solutions (Saputro et al., 2018). The main goal is for students not only to understand mathematical principles but also to be able to apply them in real-world situations (Niss, 1994). Mathematics is only "useful" to the extent that it can be applied to specific circumstances, and problem-solving uses mathematics in various scenarios (Smith, 1986).

Mathematical problem-solving abilities, the main focus of this study, are expected to provide VHS students with the cognitive experience needed to solve work-related difficulties. Learning mathematics in VHS is significantly influenced by pragmatic factors (Smith, 1986) because field mathematics is not considered mathematics(Bakker et al., 2014). As a result, the mathematics curriculum in VHS is incoherent, impossible to apply vertically and horizontally, and far from learning meaningfully (Effendi, 2014). Based on this description, mathematics education in vocational schools must be contextualized so that the teaching materials and learning processes can meet the needs of the world of work. One of the essential mathematical concepts in VHS is geometry.

Geometry is studied at all levels of education and is a mathematical discipline that builds the foundation for more complex mathematical skills (Mammarella et al., 2013; NCTM, 2000). Geometry represents a network of interconnected ideas and concepts (Couto & Vale, 2013; NCTM, 2000; Sunzuma & Maharaj, 2020). Geometry makes an exceptional contribution to the development of students' visualization skills, critical thinking, intuition, problem-solving, conjecture, deductive reasoning, and logical arguments (Jones, 2002); moreover, knowing geometry promotes awareness of the relevance of geometry in everyday life (Myers, 1991). Geometry is a complex thing for students to master at school (Tan et al., 2015). On the other hand, based on data from the Indonesian Educational Evaluation Center, geometry achievement tends to fall between 2017 and 2018 (Puspendik, 2018). They cannot solve all geometric problems (Cesaria & Herman, 2019). It is possible because students prefer something other than geometry.

Students often need to be more open to geometry due to its abstract nature and reliance on various formulas and symbols (Doli & Armiati, 2020). In general, children struggle to understand geometric concepts, reasoning, and problem-solving abilities (Gutiérrez et al., 1991; Sunzuma & Maharaj, 2020); students have difficulty understanding congruence, circle theorems, and surface areas of flat shapes (Fabiyi, 2017). At every school stage, students strive to acquire geometry; for example, elementary school students cannot recognize simple geometric shapes (Marchis, 2012). Junior high school students struggle to measure, identify angles and shapes, transform, and construct three-dimensional shapes (Özerem, 2012). In high school, it was carried out by Setyaningtyas and Rusnilawati (2019); students struggle with naming geometric shapes, describing geometric qualities, explaining relationships between cubes and blocks, and performing mathematical calculations. Thus, it is necessary to construct inductive arguments regarding geometric figures and relationships (NCTM, 2000). To overcome these problems, the purpose of this study is to apply project-based learning as a more concrete and relevant learning method, focusing on conceptual understanding rather than memorization, which includes targeted exercises and real-life applications, with specific adaptations for VHS students, is expected to improve students' geometry skills.

Methods

The research was a quasi-experiment to investigate the influence of PjBL on mathematical problem-solving ability. The effectiveness of Project Based Learning can be determined by comparing the students' math problem-solving skills in the experimental and control classes. The experimental design of this study is quasi-experimental based on sample conditions without selection due to practical, ethical, and methodological reasons applied (Campbell & Stanley, 2015), matched only pre-test and post-test control group design. An investigation was carried out by giving a pre-test to both courses to determine if their math problem-solving skills were comparable. A different treatment was given to both classes; the X symbol in the diagram above represents the experimental class, while the others represent the control class. The experimental class was treated with PjBL, while the control class received expository instructions. The PjBL treatment in this study is presented in Table 1.

Table 1. PjBL treatment in this research

Activities description	Teacher Activities	Student Activities
Introduction	The teacher conveys apperception, motivation to students, basic competencies, and learning objectives.	Students listen to apperception, motivation, basic competencies, and learning objectives carried out by the teacher.
Core activities	The teacher distributes student worksheets to students about project-based learning	Students explore project ideas based on problems presented in student worksheet
	The teacher guides students to set the theme of the project	• Students set learning context • Students in small groups divide tasks to answer problems in the worksheet
		• Students plan actual activities based on the learning context • Students browse the learning resources that support the project • Students collect tools and materials that support the project in student worksheets
		Students in small groups sketch the project to be carried out related to the topic geometry
	The teacher guides each group of students in making a project activity report	• Students implement activities • Students in small groups seek solutions to problems based on relevant learning resources • Each group makes a report and presents it in class
Closing activities	The teacher rewards students' success	• Students work on tests given by the teacher • Students confirm their understanding with the teacher's explanation

The research was conducted at State VHS 1 Majalengka. This research has gone through a process of legal clearance legal research from all the subjects involved in the research, and the subjects believe that there is no risk of physical, psychological, or legal consequences arising from their involvement in the research. The research activities began with making instruments, evaluating talent in mathematics, selecting samples, implementing learning, and analyzing research data. The research sample comprised 64 students divided into two classes, each with 32 students: the experimental and the control classes. Nonprobability sampling, particularly purposive sampling based on discussions with teachers regarding the Early Mathematics Skills (EMS) category, allowed for selecting students to meet heterogeneous criteria. However, it's important to note that non-probability sampling may limit the generalizability of the results beyond the specific sample selected. While the findings provide valuable insights into the impact of PjBL on mathematical problem-solving capacity within the sampled group, they also hold significant potential in contributing to the understanding of the impact of PjBL on mathematical problem-solving skills. The Early Mathematics Skills (EMS) category is determined by the ability to analyze the previous students' subject matter.

The research data was obtained through a math problem-solving test given to students to measure the development of their math problem-solving abilities. The indications of mathematical problem-solving refer to Sumarmo (2010) to evaluate students' proficiency in locating relevant information, constructing mathematical models from real-world scenarios, selecting approaches to solve problems, interpreting findings, and applying mathematics meaningfully. The research instrument of this research consisted of a test of the ability to solve mathematical problems. The mathematical problem-solving abilities developed in this study consist of physical, realistic, fantasy, and pure mathematical context problems (Quezada, 2020). The validity and reliability of the instrument should be evaluated through expert opinion and trials in classes other than topic studies. After completing these steps, it will be possible to determine that all the instruments designed by the researcher have met the validity and reliability standards based on the criteria provided. The validity coefficient for each test item is roughly 0.75, suggesting a high level of validity, while the reliability coefficient is 0.81, showing adequate reliability. The score on each item measures the ability to solve math problems based on the difficulty level of the questions. The math problem-solving test consists of five questions. The optimal maximum score is 50 because questions numbered 1 to 3 have a score range of 0 to 10, while questions numbered 4 and 5 have a rating range of 0 to 15.

Normality and homogeneity tests of variance data post-test and N-gain analysis start the data. The Kolmogorov-Smirnov test was used to check the two data sets for normality, and the F test was used for homogeneity of variance. The data were analyzed using the t-test on independent samples and a two-way ANOVA test with Univariate General Linear Model (GLM) analysis. The t-test on independent samples was conducted to determine differences in the ability to solve mathematical problems between the two classes. On the other hand, ANOVA was conducted to find the difference in the increase in mathematical problem-solving skills between the two classes based on the Early Mathematics Skills (EMS) category level. Hypothesis testing was carried out using a significance level of 0.05.

Results

Data from the pre-test and post-test findings regarding mathematical problem-solving abilities were obtained from the study. The initial ability of students in both classes is the same, according to the pre-test findings analysis, so the two classes of students are worthy of comparison. The disparity in the capacity of the two classes to solve math problems was addressed using post-test and N-gain data, each of which has a separate learning process. The following justifies the hypothesis to be used to compare improvements in math problem-solving skills:

1. The students' mathematical problem-solving skills in the experimental group were better than the control group.
2. There is a significant difference in the increase in mathematical problem-solving skills between students with high, medium, and low ability levels.
3. There is an interaction between the learning model factors given and the EMS category factors toward increasing mathematical problem-solving abilities.

An Independent sample t-test will be used to demonstrate the first hypothesis. Table 2 displays the test findings for variance in the mean mathematical relationship.

Table 2. The results of the different tests are based on the average posttest mathematical problem-solving ability score

Levene's Test for Equality of Variances	F	Sig.	t	Df	Sig. (2-tailed)
Equal variances assumed	10.677	.002	6.210	62	.000

Based on the calculation results in Table 2 above, the p-value is $p < .001$ for the posttest data of mathematical problem-solving ability. Based on these findings, H_0 is rejected. The experimental group's mathematical problem-solving skills were superior to the control group's. The superiority of the experimental group's mathematical problem-solving abilities compared to the control group can also be seen from the average differences in students' mathematical problem-solving skills shown in Table 3 below.

Table 3. Descriptive statistical data on posttest results of students' mathematical problem-solving skills

	Class	N	Mean	Std. Deviation	Std. Error Mean
Postest	experiment class	32	71.5313	8.85723	1.56575
	control class	32	60.3750	12.77788	2.25883

The disparity in the average score of students' mathematical problem-solving skills looks very large with a difference of 11.1563. Furthermore, a two-way analysis of variance (ANOVA) with GLM-Univariat will be used to test the second and third hypotheses. Table 4 displays the findings of the analysis.

Table 4. Analysis of variance of data on improving mathematical problem-solving abilities based on the mathematics learning model and EMS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4143.068[a]	5	828.614	180.055	.000
Intercept	209577.612	1	209577.612	45540.437	.000
Model	1654.200	1	1654.200	359.452	.000
EMS	2330.526	2	1165.263	253.207	.000
Class * EMS	121.276	2	60.638	13.176	.000
Error	266.917	58	4.602		
Total	215895.000	64			
Corrected Total	4409.984	63			

a. R Squared = .939 (Adjusted R Squared = .934)

Based on the calculation results in Table 4 above, the p-value is $p < .001$, and F count = 253.207 is more significant than F table = 3.12 at the significance level $\alpha = 0.05$ with degrees freedom 2/58 ($F_{0.05(2/58)} = 3.12$) or calculate F > F table so that H_0 is rejected. This condition indicates that the second research hypothesis is accepted, and the increase in students' mathematical problem-solving abilities in the experimental class is significantly better than in the control class. Furthermore, based on Table 4 above, the p-value is $p < .05$, and F_{count} = 13.176 is more significant than table F = 3.12 at the significance level $\alpha = 0.05$ with degrees of freedom 2/58 ($F_{0.05(2/74)} = 3.12$), so the H_0 is rejected. This condition indicates that the third research hypothesis is accepted. It shows an interaction between the learning model and the EMS category factors on students' mathematical problem-solving. The superiority of increasing the mathematical problem-solving abilities of the experimental group compared to the control group can also be seen from the average difference in the increase in students' mathematical problem-solving abilities shown in Table 5 below.

Table 5. Descriptive statistical data on increasing students' mathematical problem-solving abilities

	Class	N	Mean	Std. Deviation	Std. Error Mean
N_gain	Control class	32	.1686	.15553	.02749
	Experiment class	32	.3750	.08729	.01543

The disparity in the average score for improving students' mathematical problem-solving skills is very large with a difference of 0.2064.

Discussion

Students in the experimental group performed better than those in the control group when completing the math problem-solving test, according to the results of the independent sample t-test. In general, students' ability to solve math problems shows this, and their improvement in ability is superior to that of expository learning. The results of this research are relevant to previous studies, which state that PjBL affects students' mathematical problem-solving abilities (Chiang & Lee, 2016a; Han et al., 2016; Mettas & Constantinou, 2008; Muslim, 2017; Nurfitriyanti, 2016; Susanta et al., 2020). PjBL can inspire students to engage in real-world assignments and acquire transferable skills that apply to everyday life (Nilsook et al., 2021). PjBL is a constructive learning model that positions students as active learners, enabling them to build on previous knowledge (Santyasa et al., 2020) and have high academic involvement when studying with the PjBL model because it is facilitated with projects related to phenomena in everyday life that are interesting, challenging, and relevant to needs (Craft & Capraro, 2017). So, PjBL is more applicable to real life than learning from textbooks alone.

The PjBL implementation in this study aligns with the PjBL indicators commonly used by other researchers. Based on this, we claim that PjBL is an aspect that influences the effectiveness of the mathematical problem-solving skills of VHS School students in presenting geometric problems that apply in the context of engineering disciplines, especially building engineering in the experimental class. The implementation basis is characterized by three classifications, including (1) Pre-PjBL, (2) simple projects, and (3) models with actual or complex projects (Sudjimat et al., 2021). When learning geometry, students look enthusiastic because their learning differs from learning mathematics. Generally, mathematics learning by teachers uses a mechanistic and structuralistic approach. A mechanistic approach is a traditional approach that starts from the simple to the more complex, so humans are seen as machines in this approach. Meanwhile, the structuralistic approach uses a formal system to achieve a concept through vertical mathematization, which is formally formulated using various rules.

Geometry learning that is carried out using PjBL tends to be delivered with a horizontal approach, in which the mathematical concepts to be learned by students are raised from life phenomena, formulated informally, using a variety of concrete, semi-concrete, or semi-abstract tools using open-ended project assignments. Students in PJBL engage in interdisciplinary learning by researching, developing solutions, and creating products to address real-world problems or challenges (Sakulviriyakitkul et al., 2020). Problems in geometry are presented in the form of open problems. Through work activities in small groups of students and presenting reports related to projects that have been worked on, students become more active and able to work together in group learning based on the division of tasks in the worksheets given so that they can communicate the results of group work. Project work with groups relevant to real life motivates and entertains students in participating in learning because students feel their knowledge is more meaningful and can be applied to solve physical difficulties encountered in everyday life (Chiang & Lee, 2016b). Solving these challenges may require different cognitive processes (Wang et al., 2022). More is needed for problem solvers to know; they must also possess high cognitive skills to solve difficulties successfully (Wong, 1992). Students with limited talents face many obstacles when trying to solve problems; as a result, they give up without realizing the benefits of their efforts (Wilburne & Dause, 2017).

On the other hand, teachers must be able to formulate and provide challenging problems to their students (Cai & Hwang, 2020). Educational strategies to improve mathematical problem-solving skills must also provide opportunities for students to learn mathematics while solving problems (Yapatang & Polyiem, 2022). Problems a teacher gives can shape students' mathematics learning in their class (NCTM, 2000). PjBL settings meet students' diverse learning abilities and needs (Ubuz & Aydnyer, 2019). These characteristics and the student-centered nature of PjBL contribute to creating an effective learning environment that encourages independent learning (Zarouk et al., 2020). All students like contextualizing activities because they activate their prior knowledge and experience as their thinking, imagination, creativity, and motor skills (Ubuz & Aydnyer, 2019). According to previous research, contextualization allows all students to find meaning in lessons (Duatepe-Paksu & Ubuz, 2009), especially in developing the ability to overcome problems encountered during the continuing education process, both inside and outside of school (Shabrina & Kuswanto, 2018).

Furthermore, based on the two-way analysis of variance (ANOVA) with the GLM-Univariate, it can be concluded that the learning model and prior knowledge categories significantly improve mathematical problem-solving abilities based on the EMS category. Increased student involvement can be seen from students' enthusiasm, activeness, and critical attitude during learning, especially in connecting previous knowledge and gathering information from various sources related to project activities, making it easier for students to acquire mathematical problem-solving abilities as new knowledge. Assessment of prior knowledge has a positive effect (Dochy et al., 1999). Problem-solving requires going beyond prior experience, such as prior knowledge (Chang, 2010; Oksuz, 2009). According to research, prior knowledge plays a role in learning success (Santagata & Lee, 2019; Star et al., 2009; Williams, 2020). Prior knowledge is a requirement for constructing new knowledge. It must be sufficient for the learning process to progress towards its goal and even beyond it. The quality of students' previous instructional experience influences the formation of initial abilities. If previous learning is not practical, then the learning outcomes do not meet the desired goals—negative experiences as a mathematics student lead to substantial academic (Page & Clark, 2010).

In the learning process that has been undertaken and research results, two perspectives can cause discomfort, namely whether minimal or complete guidance is superior. PjBL is part of minimally guided learning (Sweller et al., 2007). However, the role of the teacher in improving complex problem-solving skills is critical (Ummah et al., 2020). On the other hand, the optimal learning environments for experts and beginners differ. In contrast, experts often thrive with little guidance. Practically everyone succeeds when given comprehensive and explicit instructional directions (and should not be asked to discover actual content or skills (Sweller et al., 2007). Both types of guidance must concern teachers and other researchers who will conduct similar research. The teacher is expected to be a facilitator who guides students so that when many students find it challenging to identify the concept they want to achieve, the teacher can direct them by providing minimal guidance. Students given projects during the PjBL process tend to put more effort into gaining meaningful knowledge related to the project. They can better use logical thinking in solving problems and connecting principles or concepts learned in real life (Rosales & Sulaiman, 2016). Therefore, PjBL can be used to emphasize students' role in finding their knowledge through project-based learning independently (Darmuki et al., 2023).

This research has limitations related to the guidance provided by the teacher, which is still carried out intensively to students. Students can only choose a project if the teacher uses more than one. The guidance is still carried out intensively for students because students still need to learn mathematics based on project activities. In learning design, the teacher should provide alternative projects that can be selected according to students' abilities. The potential of providing alternative projects for students to complement PjBL in achieving students' mathematical problem-solving abilities needs to be critically examined in further research.

Conclusion

The students' mathematical problem-solving skills in the experimental group performed better than the control group. In addition, PjBL can improve the mathematic problem-solving abilities of VHS students, as evidenced by its improvement compared to the control class. Geometry learning carried out using PjBL is delivered horizontally using open project assignments and provides new challenges and experiences for students. Furthermore, the results of the study show that the PjBL arrangement is claimed to be able to meet the needs of students with diverse learning abilities because it is proven that there is an interaction between the learning model and EMS category factors on students' mathematical problem-solving. Students with high initial ability can identify problems and work on requested projects with little resistance.

Meanwhile, some students in the medium group and the majority in the low group experienced more significant obstacles. However, with the teacher's guidance, students could understand the concepts to be achieved following the learning objectives. It shows that students in the low and medium groups get a more significant advantage in PjBL learning. Further research can be carried out to develop other mathematical abilities both in learning geometry and other learning that is considered relevant.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the authors have completed the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies.

Author Contributions

Mohamad Gilar Jatisunda: Conceptualization, writing - original draft, editing, and visualization; **Didi Suryadi:** Writing - review & editing, formal analysis, and methodology; **Sufyani Prabawanto:** Validation and supervision.

References

Bakker, A., Groenveld, D., Wijers, M., Akkerman, S. F., & Gravemeijer, K. P. E. (2014). Proportional reasoning in the laboratory: An intervention study in vocational education. *Educational Studies in Mathematics*, *86*(2), 211–221. https://doi.org/10.1007/s10649-012-9393-y

Barak, M. H., & Shoshana, A. (2020). Separatist biopolitics: the dual discourse of the vocational education policy in Israel. *Journal of Vocational Education & Training*, *72*(2), 297–314. https://doi.org/10.1080/13636820.2020.1721734

Billett, S. (2013). Learning through practice: beyond informal and towards a framework for learning through practice. *Revisiting Global Trends in TVET: Reflections on Theory and Practice*, 123–163. http://www.dcdualvet.org/wp-content/uploads/2013_UNESCO-UNEVOC_Revisiting-global-trends-in-TVET.pdf#page=129

Bishara, S. (2016). Creativity in unique problem-solving in mathematics and its influence on motivation for learning. *Cogent Education*, *3*(1), 1202604. https://doi.org/10.1080/2331186X.2016.1202604

Branch, L. J. (2015). The impact of project-based learning and technology on student achievement in mathematics. In *New media, knowledge practices and multiliteracies* (pp. 259–268). Springer. https://doi.org/10.1007/978-981-287-209-8_24

Cai, J., & Hwang, S. (2020). Learning to teach through mathematical problem posing: Theoretical considerations, methodology, and directions for future research. *International Journal of Educational Research*, *102*, 101391. https://doi.org/10.1016/j.ijer.2019.01.001

Campbell, D. T., & Stanley, J. C. (2015). *Experimental and quasi-experimental designs for research*. Ravenio Books. http://davidpassmore.net/courses/data/_book/Camp_and_Stanley.pdf

Capraro, R. M., & Slough, S. W. (2013). Why PBL? Why STEM? Why now? An introduction to STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. In *STEM project-based learning* (pp. 1–5). Brill Sense. http://www.academia.edu/download/37030650/a1stem-project-based-learning.pdf

Carson, J. (2007). A problem with problem solving: Teaching thinking without teaching knowledge. *The Mathematics Educator*, *17*(2). https://ojs01.galib.uga.edu/tme/article/download/1912/1817

Cesaria, A., & Herman, T. (2019). Learning obstacle in geometry. *Journal of Engineering Science and Technology*, *14*(3), 1271–1280.

Chang, C.-Y. (2010). Does problem solving= prior knowledge+ reasoning skills in earth science? An exploratory study. *Research in Science Education*, *40*(2), 103–116. https://doi.org/10.1007/s11165-008-9102-0

Chiang, C.-L., & Lee, H. (2016a). The effect of project-based learning on learning motivation and problem-solving ability of vocational high school students. *International Journal of Information and Education Technology*, *6*(9), 709–712. https://doi.org/10.7763/IJIET.2016.V6.779

Chiang, C.-L., & Lee, H. (2016b). The effect of project-based learning on learning motivation and problem-solving ability of vocational high school students. *International Journal of Information and Education Technology*, *6*(9), 709–712. https://doi.org/10.7763/IJIET.2016.V6.779

Couto, A., & Vale, I. (2013). *Preservice teachers' knowledge on elementary geometry concepts*. http://hdl.handle.net/10400.22/12510

Craft, A. M., & Capraro, R. M. (2017). Science, technology, engineering, and mathematics project-based learning: Merging rigor and relevance to increase student engagement. *Electronic International Journal of Education, Arts, and Science (EIJEAS)*, *3*(6).

Dalby, D., & Noyes, A. (2015). Connecting Mathematics Teaching with Vocational Learning. *Adults Learning Mathematics*, *10*(1), 40–49. https://eric.ed.gov/?id=EJ1077715

Darmuki, A., Nugrahani, F., Fathurohman, I., Kanzunnudin, M., & Hidayati, N. A. (2023). The impact of inquiry collaboration project based learning model of Indonesian language course achievement. *International Journal of Instruction*, *16*(2), 247–266.

Dias, A. L. B. (2015). The role of mathematics in vocational education curricula: a comparative study. *XIV Conferencia Interamericana de Educación Matemática*.

Dochy, F., Moerkerke, G., & Segers, M. (1999). The effect of prior knowledge on learning in educational practice: Studies using prior knowledge state assessment. *Evaluation & Research in Education*, *13*(3), 114–131. https://doi.org/10.1080/09500799908666952

Doli, W., & Armiati, A. (2020). Development of Mathematics Learning Tools Based on Realistic Mathematics Education for Vocational High School Students. *Journal of Physics: Conference Series*, *1554*, 12021. https://doi.org/10.1088/1742-6596/1554/1/012021

Duatepe-Paksu, A., & Ubuz, B. (2009). Effects of drama-based geometry instruction on student achievement, attitudes, and thinking levels. *The Journal of Educational Research*, *102*(4), 272–286. https://doi.org/10.3200/JOER.102.4.272-286

Effendi, M. (2014). Alternatif model organisasi kurikulum matematika SMK [Alternative model of vocational school mathematics curriculum organization]. *Jurnal HIPKIN: Inovasi Kurikulum, ISSN*, *6750*, 123–135.

Fabiyi, T. R. (2017). Geometry concepts in mathematics perceived difficult to learn by senior secondary school students in Ekiti State Nigeria. *IOSR Journal of Research & Method in Education (IOS-JRME)*, *7*, 83. https://doi.org/10.9790/7388-0701018390

Fajra, M., & Novalinda, R. (2020). Project based learning: innovation to improve the suitability of productive competencies in vocational high schools with the needs of the world of work. *International Journal of Multi Science*, *1*(08), 1–11. https://multisciencejournal.com/index.php/ijm/article/download/83/65

Fitzmaurice, O., Walsh, R., & Burke, K. (2019). The 'Mathematics Problem' and preservice post primary mathematics teachers–analysing 17 years of diagnostic test data. *International Journal of Mathematical Education in Science and Technology*, 1–23. https://doi.org/10.1080/0020739X.2019.1682700

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2011). *How to design and evaluate research in education*. New York: McGraw-Hill Humanities/Social Sciences/Languages. https://pdfs.semanticscholar.org/60b6/99eda714ac21599455741fb499dd4e68f615.pdf

Frejd, P., & Muhrman, K. (2020). Is the mathematics classroom a suitable learning space for making workplace mathematics visible?–An analysis of a subject integrated team-teaching approach applied in different learning spaces. *Journal of Vocational Education & Training*, 1–19. https://doi.org/10.1080/13636820.2020.1760337

Frey, R. F., Brame, C. J., Fink, A., & Lemons, P. P. (2022). Teaching Discipline-Based Problem Solving. *CBE—Life Sciences Education*, *21*(2), fe1. https://doi.org/10.1187/cbe.22-02-0030

Gill, O., O'Donoghue, J., Faulkner, F., & Hannigan, A. (2010). Trends in performance of science and technology students (1997–2008) in Ireland. *International Journal of Mathematical Education in Science and Technology*, *41*(3), 323–339. https://doi.org/10.1080/00207390903477426

Greenier, V. T. (2020). The 10Cs of project-based learning TESOL curriculum. *Innovation in Language Learning and Teaching*, *14*(1), 27–36. https://doi.org/10.1080/17501229.2018.1473405

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*, 101586. https://doi.org/10.1016/j.ijer.2020.101586

Gutiérrez, A., Jaime, A., & Fortuny, J. M. (1991). An alternative paradigm to evaluate the acquisition of the van Hiele levels. *Journal for Research in Mathematics Education*, *22*(3), 237–251. https://doi.org/doi.org/10.5951/jresematheduc.22.3.0237

Han, S., Rosli, R., Capraro, M. M., & Capraro, R. M. (2016). The effect of science, technology, engineering and mathematics (stem) project based learning (pbl) on students' achievement in four mathematics topics. *Journal of Turkish Science Education (TUSED)*, *13*. https://www.academia.edu/download/49266051/tusedv13s2a1.pdf

Holmes, J., & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, *26*(3), 339–366. https://doi.org/10.1080/01443410500341056

Holmes, V.-L., & Hwang, Y. (2016). Exploring the effects of project-based learning in secondary mathematics education. *The Journal of Educational Research*, *109*(5), 449–463. https://doi.org/10.1080/00220671.2014.979911

Jones, K. (2002). *Issues in the teaching and learning of geometry*.

King, B., & Smith, C. (2020). Using project-based learning to develop teachers for leadership. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *93*(3), 158–164. https://doi.org/10.1080/00098655.2020.1735289

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Krajcik, J. S., & Blumenfeld, P. C. (2006). *Project-based learning*. https://www.academia.edu/download/54752645/PBL_Article.pdf

Kurniawan, R., & Managi, S. (2018). Economic growth and sustainable development in Indonesia: an assessment. *Bulletin of Indonesian Economic Studies*, *54*(3), 339–361. https://doi.org/10.1080/00074918.2018.1450962

Kzkapan, O., & Bektaş, O. (2017). The effect of project based learning on seventh grade students' academic achievement. *Internasional Journal of Instruction*, *10*(1), 37-54 https://doi.org/10.12973/iji.2017.1013a

Lima, R. M., Dinis-Carvalho, J., Sousa, R. M., Alves, A. C., Moreira, F., Fernandes, S., & Mesquita, D. (2017). Ten years of project-based learning (PBL) in industrial engineering and management at the University of Minho. In *PBL in Engineering Education* (pp. 33–51). Brill Sense. https://brill.com/view/book/edcoll/9789463009058/BP000004.xml

MacLeod, M., & van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European Journal of Engineering Education*, *45*(3), 363–377. https://doi.org/10.1080/03043797.2019.1646210

Mammarella, I. C., Giofrè, D., Ferrara, R., & Cornoldi, C. (2013). Intuitive geometry and visuospatial working memory in children showing symptoms of nonverbal learning disabilities. *Child Neuropsychology*, *19*(3), 235–249. https://doi.org/10.1080/09297049.2011.640931

Marchis, I. (2012). Preservice Primary School Teachers' Elementary Geometry Knowledge. *Acta Didactica Napocensia*, *5*(2), 33–40.

Mettas, A. C., & Constantinou, C. C. (2008). The technology fair: A project-based learning approach for enhancing problem solving skills and interest in design and technology education. *International Journal of Technology and Design Education*, *18*(1), 79–100. https://doi.org/10.1007/s10798-006-9011-3

Muslim, S. R. (2017). Pengaruh penggunaan model project based learning terhadap kemampuan pemecahan masalah matematik peserta didik SMA [The effect of using the project based learning model on the mathematical problem solving ability of high school students]. *SJME (Supremum Journal of Mathematics Education)*, *1*(2), 88–95. https://doi.org/10.35706/sjme.v1i2.756

Myers, N. C. (1991). Writing and speaking to learn geometry. *Problems, Resources, and Issues in Mathematics Undergraduate Studies*, *1*(3), 287–294.

NCTM. (2000). *Principles and standarts for school mathematics NCTM*.

Nilsook, P., Chatwattana, P., & Seechaliao, T. (2021). The project-based learning management process for vocational and technical education. *Higher Education Studies*, *11*(2), 20–29. https://doi.org/10.5539/hes.v11n2p20

Niss, M. (1994). Mathematics in society. *Didactics of Mathematics as a Scientific Discipline*, *13*, 367–378. http://www.academia.edu/download/5910014/biehler_r.__ed.___scholz_r.w.__ed.___strasser_r.__ed.__-_didactics_of_mathematics_as_a_scientific_discipline_2002__467_.pdf#page=378

Niss, M. (2003). Mathematical competencies and the learning of mathematics: The Danish KOM project. *3rd Mediterranean Conference on Mathematical Education*, 115–124. http://www.academia.edu/download/55112695/KOMkompetenser.pdf

Nurfitriyanti, M. (2016). Model pembelajaran project based learning terhadap kemampuan pemecahan masalah matematika [Project based learning model for mathematical problem solving abilities]. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, *6*(2), 149-160. https://doi.org/10.30998/formatif.v6i2.950

Oksuz, C. (2009). Association of domain-specific knowledge and analytical ability with insight problem solving in mathematics. *International Journal of Pedagogies and Learning*, *5*(1), 138–153. https://doi.org/10.5172/ijpl.5.1.138

Özcan, Z. Ç. (2016). The relationship between mathematical problem-solving skills and self-regulated learning through homework behaviours, motivation, and metacognition. *International Journal of Mathematical Education in Science and Technology*, *47*(3), 408–420. https://doi.org/10.1080/0020739X.2015.1080313

Özerem, A. (2012). Misconceptions in geometry and suggested solutions for seventh grade students. *Procedia-Social and Behavioral Sciences*, *55*, 720–729. https://doi.org/10.1016/j.sbspro.2012.09.557

Page, S., & Clark, J. (2010). Experiences of learning and teaching mathematics: using activity theory to understand tensions in practice. *Mathematics Education Research Group of Australasia*.

Pehkonen, E. (1993). What are Finnish teacher educators' conceptions about the teaching of problem solving in mathematics? *European Journal of Teacher Education*, *16*(3), 237–256. https://doi.org/10.1080/0261976930160306

Petrosino, A. J. (2004). Integrating curriculum, instruction, and assessment in project-based instruction: A case study of an experienced teacher. *Journal of Science Education and Technology*, *13*(4), 447–460. https://doi.org/10.1007/s10956-004-1466-y

Phumeechanya, N., & Wannapiroon, P. (2014). Design of problem-based with scaffolding learning activities in ubiquitous learning environment to develop problem-solving skills. *Procedia-Social and Behavioral Sciences*, *116*, 4803–4808. https://doi.org/10.1016/j.sbspro.2014.01.1028

Pinho-Lopes, M., & Macedo, J. (2016). Project-based learning in geotechnics: Cooperative versus collaborative teamwork. *European Journal of Engineering Education*, *41*(1), 70–90. https://doi.org/10.1080/03043797.2015.1056099

Placklé, I., Könings, K. D., Struyven, K., Libotton, A., van Merriënboer, J. J. G., & Engels, N. (2020). Powerful learning environments in secondary vocational education: towards a shared understanding. *European Journal of Teacher Education*, *43*(2), 224–242. https://doi.org/10.1080/02619768.2019.1681965

Puspendik. (2018). *Hasil TIMSS 2018 diagnosa hasil untuk perbaikan mutu dan peningkatan capaian*. [TIMSS 2018 results diagnose results for improving quality and increasing achievement].

Quezada, V. D. (2020). Difficulties and Performance in Mathematics Competences: Solving Problems with Derivatives. *J. Eng. Pedagogy*, *10*(4), 35–53.

Rosales, J. J., & Sulaiman, F. (2016). Students' sense making and effort toward projectbased learning in learning physics. *International Journal of Education and Research*, *4*(9), 29–40. https://ijern.com/journal/2016/September-2016/03.pdf

Sakulviriyakitkul, P., Sintanakul, K., & Srisomphan, J. (2020). The design of a learning process for promoting teamwork using project-based learning and the concept of agile software development. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(3), 207–222. https://doi.org/10.3991/ijet.v15i03.10480

Santagata, R., & Lee, J. (2019). Mathematical knowledge for teaching and the mathematical quality of instruction: a study of novice elementary school teachers. *Journal of Mathematics Teacher Education*, 1–28. https://doi.org/10.1007/s10857-019-09447-y

Santos, L. B., Xavier, P. H. F., Santos, J. V. C., & Sampaio, R. R. (2020). Teaching of Ordinary Differential Equations Using the Assumptions of the PBL Method. *Int. J. Eng. Pedagog.*, *10*(3), 7–20. https://doi.org/10.3991/ijep.v10i3.12015

Santyasa, I. W., Rapi, N. K., & Sara, I. (2020). Project based learning and academic procrastination of students in learning physics. *International Journal of Instruction*, *13*(1), 489–508. https://doi.org/10.29333/iji.2020.13132a

Saputro, A. D., Rohaeti, E., Prodjosantoso, A. K., & others. (2018). Promoting critical thinking and problem solving skills of Preservice elementary teachers through process-oriented guided-inquiry learning (POGIL). *International Journal of Instruction*, *11*(4), 777–794.

Sari, N. M., Yaniawati, P., Kartasasmita, B. G., & others. (2019). The Effect of Different Ways in Presenting Teaching Materials on Students' Mathematical Problem Solving Abilities. *International Journal of Instruction*, *12*(4), 495–512. https://doi.org/10.29333/iji.2019.12432a

Setyaningtyas, H., & Rusnilawati, M. P. (2019). *Analisis kesulitan belajar siswa kelas v pada materi bangun ruang dan alternatif pemecahannya berdasarkan teori Van Hiele di SD Negeri 1 Gatak Delanggu*.[Analysis of class V students' learning difficulties in building space material and alternative solutions based on Van Hiele Theory at SD Negeri 1 Gatak Delanggu]. Universitas Muhammadiyah Surakarta.

Setyarini, T., Mustaji, M., & Jannah, M. (2020). The effect of project-based learning assisted pangtus on creative thinking ability in higher education. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(11), 245–251. https://doi.org/10.3991/ijet.v15i11.12717

Shabrina, & Kuswanto, H. (2018). Android-assisted mobile physics learning through Indonesian batik culture: Improving students' creative thinking and problem solving. *International Journal of Instruction*, *11*(4), 287–302.

Smith, S. (1986). Problem solving in mathematics. *Early Years*, *6*(2), 15–24. https://doi.org/10.1080/0957514860060203

Sonnert, G., Sadler, P. M., Sadler, S. M., & Bressoud, D. M. (2015). The impact of instructor pedagogy on college calculus students' attitude toward mathematics. *International Journal of Mathematical Education in Science and Technology*, *46*(3), 370–387. https://doi.org/10.1080/0020739X.2014.979898

Star, J. R., Rittle-Johnson, B., Lynch, K., & Perova, N. (2009). The role of prior knowledge in the development of strategy flexibility: The case of computational estimation. *ZDM*, *41*(5), 569–579. https://doi.org/10.1007/s11858-009-0181-9

Sudjimat, D. A., Nyoto, A., & Romlie, M. (2021). Implementation of project-based learning model and workforce character development for the 21st century in vocational high school. *International Journal of Instruction*, *14*(1), 181–198. https://doi.org/10.29333/iji.2021.14111a

Sumarmo, U. (2010). *Berpikir dan disposisi matematik: Apa, mengapa, dan bagaimana dikembangkan pada peserta didik.[Mathematical thinking and disposition: What, why, and how are developed in students]*. FPMIPA UPI.

Sunzuma, G., & Maharaj, A. (2020). In-service Zimbabwean teachers' obstacles in integrating ethnomathematics approaches into the teaching and learning of geometry. *Journal of Curriculum Studies*, 1–20. https://doi.org/10.1080/00220272.2020.1825820

Susanta, A., Susanto, E., & Rusdi. (2020). Efektivitas project based learning terhadap kemampuan pemecahan masalah dan berpikir kritis mahasiswa. [The effectiveness of project based learning on students' problem solving and critical thinking abilities]. *Jurnal Theorems*, *5*(1), 61–68.

Sweller, J., Kirschner, P. A., & Clark, R. E. (2007). Why minimally guided teaching techniques do not work: A reply to commentaries. *Educational Psychologist*, *42*(2), 115–121. https://doi.org/10.1080/00461520701263426

Tan, C.-S., Tan, S.-A., Hashim, I. H. M., Lee, M.-N., Ong, A. W.-H., & nor Binti Yaacob, S. (2019). Problem-solving ability and stress mediate the relationship between creativity and happiness. *Creativity Research Journal*, *31*(1), 15–25. https://doi.org/10.1080/10400419.2019.1568155

Tan, T. H., Tarmizi, R. A., Yunus, A. S. M., & Ayub, A. F. M. (2015). Understanding the primary school students' van Hiele levels of geometry thinking in learning shapes and spaces: A Q-methodology. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(4), 793–802. https://doi.org/10.12973/eurasia.2015.1439a

Tsybulsky, D., Gatenio-Kalush, M., Ganem, M. A., & Grobgeld, E. (2020). Experiences of preservice teachers exposed to project-based learning. *European Journal of Teacher Education*, 1–16. https://doi.org/10.1080/02619768.2019.1711052

Ubuz, B., & Aydnyer, Y. (2019). Project-based geometry learning: Knowledge and attitude of field-dependent/independent cognitive style students. *The Journal of Educational Research*, *112*(3), 285–300. https://doi.org/10.1080/00220671.2018.1502138

Ummah, I. K., Yuliati, N., & others. (2020). The effect of jumping task based on creative problem solving on students' problem solving ability. *International Journal of Instruction*, *13*(1), 387–406.

Vye, N. J., Goldman, S. R., Voss, J. F., Hmelo, C., & Williams, S. (1997). Complex mathematical problem solving by individuals and dyads. *Cognition and Instruction*, *15*(4), 435–484. https://doi.org/10.1207/s1532690xci1504_1

Wang, L., Zeng, J., Ran, X., Cui, Z., & Zhou, X. (2022). Different cognitive mechanisms for process-open and process-constrained problem solving. *ZDM–Mathematics Education*, 1–13. https://doi.org/10.1007/s11858-022-01373-3

Wilburne, J. M., & Dause, E. (2017). Teaching self-regulated learning strategies to low-achieving fourth-grade students to enhance their perseverance in mathematical problem solving. *Investigations in Mathematics Learning*, *9*(1), 38–52. https://doi.org/10.1080/19477503.2016.1245036

Williams, K. L. (2020). Contextualizing math-related strengths and math achievement: Positive math orientations, social supports and the moderating effects of prior math knowledge. *Journal for STEM Education Research*, *3*(3), 317–342. https://doi.org/10.1007/s41979-021-00051-5

Wong, P. (1992). *Metacognition in mathematical problem solving*. https://doi.org/10.1080/02188799208547691

Yapatang, L., & Polyiem, T. (2022). Development of the mathematical problem-solving ability using applied cooperative learning and Polya's problem-solving process for grade 9 students. *Journal of Education and Learning*, *11*(3), 40–46. https://doi.org/10.5539/jel.v11n3p40

Zarouk, M., Olivera, E., Peres, P., & Khaldi, M. (2020). The impact of flipped project-based learning on self-regulation in higher education. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(17), 127–147. https://doi.org/10.3991/ijet.v15i17.14135