



## Optimising Mathematics Teacher Candidates' Complex Problem-Solving Skills: A Comprehensive Analysis of the Effectiveness of the Problem-Based Learning Model

Megita Dwi Pamungkas<sup>1,\*</sup>, Fadhilah Rahmawati<sup>1</sup>, Irka Lestari<sup>1</sup>, Jaka Wijaya Kusuma<sup>2</sup>, Kintoko<sup>3</sup>, & Eko Andy Purnomo<sup>4</sup>

<sup>1</sup>Universitas Tidar, Magelang, Indonesia

<sup>2</sup>Universitas Bina Bangsa, Serang, Indonesia

<sup>3</sup>Universitas PGRI Yogyakarta, Yogyakarta, Indonesia

<sup>4</sup>Universitas Muhammadiyah Semarang, Semarang, Indonesia

### Abstract

Complex problem-solving" ability is a 21st-century skill students need to solve dynamically changing problems. Students of prospective mathematics teachers are said to master complex problem situations if possible. Therefore, a learning model is needed that can improve the ability to solve complex problems for prospective mathematics teacher students, one of which uses problem-based learning (PBL). The purpose of this study is to get an overview of improving the ability to solve complex problems of prospective mathematics teacher students after learning with the Problem-Based Learning (PBL) model at Tidar University with the subject of second-semester students of the Mathematics Education Study Program. This research will be conducted using a quasi-experimental method, with a nonequivalent control group pretest-posttest research design. Research instruments are in the form of complex problem-solving tests, observation sheets on learning implementation, and interview guidelines. The results showed that PBL is more effective than conventional learning in complex problem-solving skills. In addition, the results also show that problem-based learning (PBL) is effective in improving the complex problem-solving ability of prospective mathematics teacher students. The results of the increased test with N-Gain obtained an average of 0.43, which is in the category of moderate increase.

**Keywords:** Complex problem solving, problem-based learning, prospective mathematics teacher students

(\*) Corresponding Author: [megitadwip@untidar.ac.id](mailto:megitadwip@untidar.ac.id)

**How to Cite:** Pamungkas et al. (2024). Optimising mathematics teacher candidates' complex problem-solving skills: A comprehensive analysis of the effectiveness of the problem-based learning model. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, 14(2), 419-430. <http://dx.doi.org/10.30998/formatif.v14i2.28014>

### INTRODUCTION

For a long time, mathematical problem-solving has been considered a crucial component of mathematics and mathematics education. According to Funke (2012), problem-solving techniques are deemed elegant if they exhibit clarity, simplicity, and inventiveness and successful if they result in the resolution of a specific issue with little effort. Schindler and Lilienthal (2022) claim that the solution to difficulties is to constantly flip things over in the mind until an idea comes to you naturally. On the other hand, a considerable reliance on previous experiences and knowledge is also present.

Complex Problem Solving (CPS) is a well-established concept today, and it has even impacted major tests like PISA (Programme for International Student Assessment) (OECD, 2023). CPS is thus one of the most crucial skills that will be required in the future, according to the World Economic Forum (Agenda, 2015). Funke (2010) says that

solving complex problems is a difficult cognitive skill that requires two main mental processes: (a) understanding a problem scenario that is not clear and (b) using what you know to solve problems by reaching your own goals (Fischer et al., 2017; Kroner et al., 2005). According to Gnaldi et al. (2020), there is a strong correlation between CPS and academic success. Funke (2014) says that someone has mastered a complex problem situation if they can use procedural skills to manage an environment that is constantly changing and is made up of interconnected variables, create an ever-updated representation of the problem, and find relevant information that was hidden at first.

Problem-solving abilities are emphasised in the mathematics learning process because, in reality, the majority of educators hold the view that learning outcomes are always connected to mathematics instruction. Data from early research indicate that most aspiring math teachers still place themselves in the beginner group when it comes to handling challenging issues (Pamungkas et al., 2023). In order to improve the complicated problem-solving skills of students who want to become math teachers, educators must adopt learning activities. We use a learning paradigm known as problem-based learning (PBL).

According to Arends (2012), PBL is also known as genuine learning, grounded education, and project-based instruction. PBL exposes students to authentic and significant issues that might act as a springboard for further study (Arends, 2012). Students' engagement with real-life scenarios is the aim of such learning. The education enhances their problem-solving abilities and mentality. Furthermore, PBL helps someone get used to understanding and resolving their difficulties (Farida et al., 2021).

Moreover, the study by Pamungkas and Franita (2019) demonstrates that the PBL learning approach is excellent for developing mathematical thinking abilities. Research findings from the study of Amalia et al. (2017) also showed that PBL is useful for enhancing students' capacity to solve mathematical problems. Research on the impact of the PBL paradigm on sophisticated problem-solving skills has not yet been done, according to the evaluation of the aforementioned papers. Given the aforementioned concerns, the study question is: To what extent does the PBL approach improve the sophisticated problem-solving skills of students aspiring to become math teachers?

Problem-based learning (PBL) is a learning approach where students work together to find solutions to complex problems. This learning also involves students interpreting and explaining real-world phenomena and building their understanding of them (Boye & Agyei, 2023). Problem-based learning is an educational approach that can significantly enhance students' problem-solving abilities (Amalia et al., 2017). Evendi et al. (2022) also said that problem-based learning is a constructivist learning model and a student-centred learning approach that requires students to reflect from different points of view and show they can communicate and work together.

PBL contains the core of introducing students to real and meaningful problems that can serve as a springboard for research (Arends, 2012). The PBL model is based on the assumption that confusing and undefined problems can stimulate students' curiosity and involve them in the investigation (Arends, 2012). In addition, this learning helps students become more skilled in problem-solving and encourages them to participate in teams (Fatwa et al., 2019).

PBL is a learning plan prepared to enhance learning outcomes and requires students to learn the material by solving a problem (Azmi et al., 2014). Based on the definitions of several experts mentioned, it can be concluded that problem-based learning is a learning model that presents problems to students, thereby training them to solve issues, including complex problems in mathematics.

Two main cognitive processes make up complex problem-solving (Funke, 2010): (a) the need to gather information about a problem that is not clear and (b) the use of

knowledge to reach self-set problem-solving goals (Fischer et al., 2017; Kroner et al., 2005). CPS is highly correlated with educational achievement (Ederer et al., 2015). Wüstenberg et al. (2012) say that someone has mastered a complex problem situation if they can find it relevant. However, initially, hidden information creates an up-to-date representation of the problem, and procedural skills are used to manage an environment of changing variables that are all connected. Most real-world problems are complex. Unlike simple, linear, well-structured problems that have a single direct solution, solving complex problems involves more sophisticated cognitive processing to effectively and accurately address the inherent complexity and uncertainty in the problem.

CPS is a form of problem-solving, particularly in complex and interactive situations, that allows us to acquire knowledge and apply it simultaneously and independently of specific content. According to Fischer et al. (2017), the process of complex problem-solving consists of two steps: 1. Getting knowledge: In order to fully understand the problem, the person solving it must systematically gather information (seek informative data), properly integrate this information into the situational model (seek adequate hypotheses), and selectively focus on the most important aspects; 2. Applying knowledge: Using the knowledge gained, the person solving the problem must make a series of dynamic decisions and continuously monitor the outcomes of those decisions in order to solve the problem at hand systematically.

Dealing with complex and interactive situations like that requires more problem-solving skills (Greiff et al., 2015; Molnar & Csapo, 2017). This series of complex problem-solving operations is the ability required for someone to solve non-routine problems, particularly in mathematics. In more detail, Funke (2010) named five traits of complex problems: 1) complexity that requires reducing information; 2) opacity that requires systematic information creation; 3) interconnectedness that requires problem modelling; 4) dynamics that require predicting and controlling future developments; and 5) evaluation and prioritisation (Greiff et al., 2015). Characteristics (1)–(3) can primarily be included in the first component of knowledge acquisition, while (4) and (5) primarily adhere to the second component, knowledge application (Funke, 2014). This demonstrates the close relationship between CPS and mathematics.

Based on the above explanation, the limitation of complex problem-solving in this research is the ability of prospective mathematics teacher students to solve complex problems or issues. The problems that are being talked about are complex ones because the situation is complicated, variables are linked, information is not clear, the situation changes over time, and the problem needs to be evaluated with certain factors in mind.

Mathematics teacher candidates are students who are pursuing education in the Mathematics Education Study Program. This study involves second-semester prospective mathematics teacher students enrolled in the Mathematics Education Study Program at the Faculty of Teacher Training and Education Sciences, Tidar University. In this study, prospective mathematics teacher students will solve complex problems or issues. These complex problems pose significant obstacles for students as they attempt to solve them.

## **METHODS**

### *Research Design*

The approach in this research is quantitative. This study uses two groups: one group as the experimental group receiving treatment in the form of problem-based learning and the other group as the control group receiving conventional learning treatment. The following figure illustrates the research design in question.

Experiment class	pretest	<i>PBL</i>	posttest
Control class	pretest	<i>DL</i>	posttest

Figure 1. Nonequivalent control group pretest-posttest research design

Explanation:

Pretest = test of complex problem-solving ability before treatment

PBL = implementation of problem-based learning

DL = application of direct learning

Posttest = test of complex problem-solving ability after treatment

*Research Instrument*

The instruments used in this study are the complex problem-solving test administered twice, namely the pre-test and post-test, an observation sheet for the implementation of learning, and an interview guideline. The following are indicators of complex problem-solving ability.

Table 1. Indicators of Complex Problem-Solving Ability

Aspek	Indikator	Sub Indikator
<i>knowledge acquisition</i>	Orientasi	1. Menemukan pertanyaan pada masalah
	<i>Conceptualization</i>	1. Menemukan informasi yang ada pada masalah 2. Menghubungkan informasi-informasi yang sudah didapatkan
	<i>Developing algorithmic design</i>	1. Menyusun rencana untuk memecahkan masalah 2. Membuat langkah-langkah apa yang dibutuhkan untuk memecahkan masalah
<i>knowledge application</i>	<i>Develop a strategy to solve</i>	1. Menggunakan cara akan yang digunakan untuk memecahkan masalah

Another instrument is the observation sheet for the implementation of learning, which refers to the steps of the PBL model and conventional learning. All instruments will undergo a validation process so that when used in the research, they are already declared valid. There are three validators, namely, one mathematics content expert and two mathematics education learning experts. The data collection techniques used are conducting tests, observations, in-depth interviews, and documentation. Data is explored based on the subjects' answer sheets from the complex problem-solving ability test, interviews, documentation, and observation sheets of the implementation of learning.

*Data Analysis Techniques*

The data analysis in this study is outlined as follows.

**1. Prerequisite Test**

**a. Normality Test**

The normality test is used to determine whether the data is normally distributed or not using the Shapiro-Wilk test. The test was conducted on the scores of the complex problem-solving ability test. The statistical assumptions are:

H<sub>0</sub>: The data being tested is normally distributed.

H<sub>1</sub>: tested data is not normally distributed.

The normality test is conducted using SPSS with the decision criteria that if the value of  $\rho > 0.05$ , then  $H_0$  is accepted, meaning the data is normally distributed. If the value of  $\rho < 0.05$ , then  $H_1$  is accepted, meaning the data is not normally distributed

**b. Homogeneity Test**

The homogeneity test is conducted to determine whether the obtained data has homogeneous or non-homogeneous variance. The test is conducted using Levene's test of homogeneity of variance. The statistical hypothesis in the homogeneity test is

$H_0$ : The data being tested has a homogeneous variance.

$H_1$ : The data being tested has a non-homogeneous variance.

Decision-making is based on the following criteria. If  $\rho > 0.05$ , then  $H_0$  will be accepted, meaning the data has a homogeneous variance. If  $\rho < 0.05$ , then  $H_0$  will be rejected, meaning the data has a non-homogeneous variance.

**2. Average Similarity Test**

An average similarity test was conducted to determine whether there is a difference in the average pre-test data of the sample in this study. The test used in this study is the Independent sample t-test. The formula is as follows.

$$t_{hit} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

(Sugiyono, 2016)

where:

$\bar{X}_1$  = Mean of the experimental class

$\bar{X}_2$  = Mean of the control class

$n_1$  = many subjects from the experimental class

$n_2$  = many subjects from the control class

$s_1^2$  = variance of the experimental class

$s_2^2$  = variance of the control class

The hypothesis used is:

$H_0$ : There is no difference in the average pre-test complex problem-solving ability between the experimental class and the control class

$H_1$ : There is a difference in the average pre-test scores of complex problem-solving abilities between the experimental class and the control class.

The decision is made with the following criteria: If the sig. (2-tailed) value  $> \alpha = 5\%$ , then  $H_0$  is accepted, meaning there is no difference in the average pre-test complex problem-solving ability between the experimental class and the control class. If the sig. (2-tailed) value  $< \alpha = 5\%$ , then  $H_0$  is rejected, meaning there is a difference in the average pre-test complex problem-solving ability between the experimental class and the control class.

**3. Hypothesis Testing**

After conducting the normality test and the homogeneity test, the next step is to conduct the hypothesis test. If the obtained data is normally distributed and homogeneous, a sample t-test is then conducted for each class. The sample t-test is used to see whether the sample mean is greater than or less than the predetermined KKM value. The KKM value determined in this study is 80. Here are the hypotheses used.

$H_0$ :  $\mu \leq 80$  (Average score of complex problem-solving ability  $\leq 80$ )

$H_1$ :  $\mu > 80$  (Average score of complex problem-solving ability  $> 80$ )

The decision-making criteria used are as follows: If the sig. value (2-tailed)  $> \alpha = 5\%$ , then  $H_0$  is rejected, and if the sig. value (2-tailed)  $< \alpha = 5\%$ , then  $H_0$  is accepted. In this study, both the PBL model and the conventional learning model are considered effective if  $H_0$  is rejected or  $H_1$  is accepted. The formula for the One Sample t-test statistic is as follows.

$$t_{hit} = \frac{\bar{X} - \mu_0}{\left(\frac{SD}{\sqrt{N}}\right)}$$

(Sugiyono, 2016)

where:

- $t_{hit}$  = Calculated t value
- $\bar{X}$  = Sample average
- $\mu_0$  = Parameter value
- $SD$  = Sample Standard Deviation
- $N$  = Number of sample members

Next, the calculation of the significant improvement in complex problem-solving abilities in the PBL and K classes was conducted. The data used for calculating the improvement in complex problem-solving ability are the pretest and posttest data. The calculation of the magnitude of improvement in complex problem-solving ability uses the normalised gain equation (Hake, 2002), namely:

$$\langle g \rangle = \frac{\langle S_{post} \rangle - \langle S_{pre} \rangle}{\langle S_{m\ ideal} \rangle - \langle S_{pre} \rangle}$$

Where:

- $\langle g \rangle$  = normalised average gain score
- $\langle S_{pre} \rangle$  = average pretest score
- $\langle S_{post} \rangle$  = average posttest score
- $S_{m\ ideal}$  = ideal maximum score

Table 2. Interpretation of Normalized Average Gain Scores

Nilai $\langle g \rangle$	Criteria
$\langle g \rangle \geq 0,7$	Tinggi
$0,7 > \langle g \rangle \geq 0,3$	Sedang
$\langle g \rangle < 0,3$	Rendah

## RESULTS & DISCUSSION

### Results

The research was conducted at Tidar University from June to August 2023 on second-semester students of the 2022/2023 academic year. The research was conducted in class 01 as the experimental class and class 02 as the control class. In the experimental class, learning was conducted using the PBL model, while in the control class, learning was conducted using the conventional model. After the treatment was given, an analysis was conducted aimed at testing the research hypothesis.

#### 1. Preliminary Data Analysis

The test was conducted to see whether the initial abilities of students in complex problem-solving are balanced or not. The initial data used consists of pre-test results. The

tests conducted include normality tests, homogeneity tests, and mean balance tests. The results of the tests are as follows.

**a. Normality Test**

Normality testing was conducted using the Shapiro-Wilk test. The results of the initial data normality test are shown in Table 3.

Table 3. Results of the Initial Data Normality Test Calculation

Class	<i>sig</i>	Conclusion
Experiment	0,072	normally distributed
Control	0,067	normally distributed

The results of the test indicate that it is accepted. Therefore, it can be said that both data classes are normally distributed.

**b. Homogeneity Test**

The homogeneity test was conducted using Levene’s test of homogeneity of variance. The results of the homogeneity test are shown in Table 4.

Table 4 Results of the Initial Data Homogeneity Test Calculation

Class	<i>n</i>	<i>sig</i>	Conclusion
Experiment	42	0,083	$H_0$ Accepted
Control	42		

Table 4. shows that the hypothesis is accepted. Thus, it can be said that both variances are homogeneous.

**c. Average Equality Test**

The average balance test was conducted using the Independent Sample T-test. The results of the average balance test are shown in the following table 5.

Table 5. Results of the Average Equality Test

Class	$\bar{X}$	<i>sig</i>	Conclusion
Experiment	45,67	0,067	$H_0$ accepted
Control	44,78		

Table 5 shows that the null hypothesis is accepted. Thus, it is stated that there is no significant difference in the complex problem-solving abilities of students before the research.

**2. Final Data Analysis**

The test was conducted to determine the difference in complex problem-solving abilities of prospective mathematics teacher students in both research classes after the treatment. The final data were obtained from the results of the post-test on complex problem-solving ability. In the final analysis, normality, homogeneity, mean equality and hypothesis testing were conducted. The results of the final data testing are as follows.

**a. Normality Test**

Normality testing was conducted using the Shapiro-Wilk test. The results of the initial data normality test are shown in the following Table 6.

Table 6. Results of the Final Data Normality Test Calculation

Class	sig	Conclusion
Experiment	0,084	Normally distributed
Control	0,074	Normally distributed

The results of the test indicate that it is accepted. Therefore, it can be said that both data classes are normally distributed.

**b. Homogeneity Test**

The homogeneity test was conducted using Levene’s test of homogeneity of variance. The results of the homogeneity test are shown in Table 7.

Table 7. Results of the Final Data Homogeneity Test Calculation

Class	n	sig	Conclusion
Experiment	42	0,083	$H_0$ accepted
Control	42		

Table 7 shows that  $sig > 0,05$ , and then  $H_0$  is accepted. Thus, it can be said that both variances are homogeneous.

**c. Average Equality Test**

The testing of the final data balance was conducted using the Independent Sample T-Test. The results of the average balance test are shown in Table 8.

Table 8. Results of the Average Data Balance Test

Class	$\bar{X}$	sig	Conclusion
Experiment	83,46	0,043	$H_0$ rejected
Control	79,67		

Based on Table 8, it is shown that  $sig = 0,043 < 0,05$  then  $H_0$  is rejected. Thus, it can be concluded that there is a significant difference in the complex problem-solving abilities of prospective mathematics teacher students in both classes after the treatment was given.

**d. Hypothesis Test**

After conducting the normality test and the homogeneity test, the next step is to conduct the hypothesis test. If the obtained data is normally distributed and homogeneous, a One Sample t-test is then conducted for each class. Here are the test results for both classes.

Table 9. Results of the One Sample t-test

Class	$\bar{X}$	sig	Conclusion
Experiment	83,46	0,061	$H_0$ rejected
Control	79,67	0,048	$H_0$ accepted

In this study, both the PBL model and the conventional learning model are considered effective if  $H_0$  is rejected or  $H_1$  is accepted. Based on the data above, the decision to reject  $H_0$  is found in the experimental class that uses PBL. Meanwhile, in the control class or the one using conventional learning, it concludes that the learning is not effective for complex problem-solving skills.

After it was found that there was a difference between before and after receiving problem-based learning and conventional learning, an N-Gain test was

conducted to measure the improvement in complex problem-solving skills in the experimental class. The results of the improvement test with N-Gain obtained an average of 0.43, which falls into the moderate improvement category. It can be concluded that problem-based learning (PBL) is effective in improving the complex problem-solving skills of prospective mathematics teacher students. Here are the N-Gain calculation results for the experimental class.

Table 10. N-Gain Test of the Experimental Class

	Score		N	Category
	Pretest	Posttest		
Mean	45,67	83,46	0,43	Medium

### **Discussion**

This study aimed to examine the effectiveness of the Problem-Based Learning (PBL) model in enhancing the complex problem-solving skills of mathematics teacher candidates. The findings indicate that PBL significantly contributed to the development of these skills, suggesting its potential as a transformative approach in teacher education. PBL has long been recognised for its ability to engage learners in real-world problem-solving contexts, promoting critical thinking, collaboration, and autonomy (Bridges, 2019). The results of this study align with this established body of research, showing that when mathematics teacher candidates were exposed to PBL scenarios, their problem-solving skills improved. This improvement can be attributed to the student-centered nature of PBL, which encourages students to take ownership of their learning through inquiry-based tasks.

PBL has long been recognised as an effective pedagogical model for developing critical thinking, problem-solving, and collaborative skills. In line with the work (Savery, 2019), the results of this study demonstrate that PBL enhances the problem-solving abilities of students by providing them with authentic, real-world problems that encourage deeper learning and reflection. By engaging in collaborative problem-solving, teacher candidates were better prepared to implement cooperative learning strategies in their future classrooms, an essential element of modern mathematics instruction. Gijlers and Jong (2013) noted that such skills are essential for teachers, who must be able to work effectively with colleagues and students. The collaborative nature of PBL allowed teacher candidates to share their ideas, learn from each other, and develop a range of solution strategies. This experience mirrors the collaborative practices they will encourage in their future classrooms.

Moreover, the PBL model's emphasis on real-world applications allowed candidates to relate abstract mathematical concepts to practical contexts. This approach mirrors the recommendations of Coles and Heliwell (2023), who emphasise the importance of bridging the gap between theory and practice in teacher preparation. For mathematics teacher candidates, this connection between mathematical theory and real-world application is crucial, as it helps them view mathematics not as a set of isolated concepts but as a dynamic tool for solving everyday problems. The application of PBL also demonstrated significant growth in the candidates' ability to connect mathematical concepts with real-world scenarios. This is consistent with Jonassen (2011) assertion that PBL promotes meaningful learning by contextualising abstract concepts, making them more relevant and accessible.

While the results are promising, some challenges were observed. A few teacher candidates struggled with the open-ended nature of the problems, finding it difficult to

navigate tasks without a clear step-by-step guide. This supports the concerns raised by (Alfares, 2021), who pointed out that although PBL promotes deep learning, it may be overwhelming for some students, especially those who are more accustomed to structured, direct instruction. This indicates the need for appropriate scaffolding in PBL environments to support students as they navigate complex tasks. Future studies could explore how to balance the open-ended nature of PBL with structured guidance better to accommodate students with varying levels of prior experience. Moreover, the level of motivation and engagement among the teacher candidates was a critical factor in the success of PBL. The findings support Wijnia et al. (2024), who emphasised the role of motivation in the effectiveness of PBL. Teacher candidates who were highly engaged in the learning process demonstrated greater problem-solving success and deeper understanding.

## CONCLUSION

In summary, the results of this study contribute to the growing body of literature advocating for the use of PBL in teacher education. PBL proved to be an effective approach for enhancing the problem-solving skills of mathematics teacher candidates, fostering both cognitive and collaborative growth. To optimise its effectiveness, however, careful consideration should be given to the varying levels of readiness among students, and further research is needed to refine PBL implementation strategies in teacher education.

## ACKNOWLEDGEMENT

The authors thank the Institute for Research and Community Service of Universitas Tidar (LPPM) for their support in this research.

## REFERENCES

- Agenda, I. (2015). *New Vision for Education Unlocking the Potential of Technology*. World Economic Forum.
- Alfares, N. (2021). The Effect of Problem-Based Learning on Students' Problem-Solving Self-Efficacy through Blackboard System in Higher Education. *International Journal of Education and Practice*, 9(1), 185–200. <https://doi.org/10.18488/journal.61.2021.91.185.200>
- Amalia, E., Surya, E., & Syahputra, E. (2017). The Effectiveness of Using Problem-Based Learning (PBL) in Mathematics Problem Solving Ability for Junior High School Students. *Ijariie*, 3(2), 3402–3406.
- Arends, R. I. (2012). *Learning to Teach (Ninth Edition)*. The McGraw-Hill Companies, Inc.
- Azmi, B. M., Irzani, & Khusnial, N. L. (2014). Efektivitas Strategi Probelm Based Learning (PBL) Terhadap Kemampuan Berfikir Kreatif Peserta Didik. *Beta: Jurnal Tadris Matematika*, 7(2), 108–119.
- Boye, E. S., & Agyei, D. D. (2023). Effectiveness of problem-based learning strategy in improving teaching and learning of mathematics for pre-service teachers in Ghana. *Social Sciences and Humanities Open*, 7(1), 100453. <https://doi.org/10.1016/j.ssaho.2023.100453>

- Bridges, S. M. (2019). Problem-Based Learning in Teacher Education. *Interdisciplinary Journal of Problem-Based Learning*, 13(1). <https://doi.org/10.7771/1541-5015.1866>
- Coles, A., & Heliwell, T. (2023). The role of mathematics teacher educators in preparing teachers of mathematics to respond to global challenges within their classrooms. *London Review of Education*, 21(1), 1–13.
- Ederer, P., Nedelkoska, L., Patt, A., & Castellazzi, S. (2015). What do employers pay for employees' complex problem-solving skills? *International Journal of Lifelong Education*, 34(4), 430–447. <https://doi.org/10.1080/02601370.2015.1060026>
- Evendi, E., Kusaeri, A., Sucipto, L., Pardi, M. H. H., Bayani, F., & Prayogi, S. (2022). Assessing students' critical thinking skills viewed from cognitive style: Study on implementation of problem-based e-learning model in mathematics courses. *EURASIA Journal of Mathematics, Science and Technology Education*, 18(7), 1–15.
- Farida, R. N., Qohar, A., & Rahardjo, S. (2021). Analisis Kemampuan Literasi Matematis Siswa SMA Kelas X Dalam Menyelesaikan Soal Tipe Pisa Konten Change and Relationship. *Jurnal Cendekia : Jurnal Pendidikan Matematika*, 5(3), 2802–2815. <https://doi.org/10.31004/cendekia.v5i3.972>
- Fatwa, V. C., Septian, A., & Inayah, S. (2019). Kemampuan Literasi Matematis Siswa melalui Model Pembelajaran Problem Based Instruction. *Mosharafa: Jurnal Pendidikan Matematika*, 8(3), 389–398. <https://doi.org/10.31980/mosharafa.v8i3.535>
- Fischer, A., Greiff, S., & Funke, J. (2017). The history of complex problem-solving. In *The Nature of Problem Solving: Using Research to Inspire 21st Century Learning* (pp. 107–121). OECD Publishing. <https://doi.org/10.1787/9789264273955-9-en>
- Funke, J. (2010). Complex problem solving: a case for complex cognition? *Cognitive Processing*, 11, 133–142. <https://doi.org/10.1007/s10339-009-0345-0>
- Funke, J. (2012). Complex Problem Solving. In *Encyclopedia of the Sciences of Learning* (pp. 682–685). Springer Berlin Heidelberg. <https://doi.org/10.1007/978-1-4419-1428-6>
- Funke, J. (2014). Analysis of minimal complex systems and complex problem-solving require different forms of causal cognition. *Frontiers in Psychology*, 5, 739. <https://doi.org/10.3389/fpsyg.2014.00739>
- Gijlers, H., & Jong, T. De. (2013). Using Concept Maps to Facilitate Collaborative Simulation-Based Inquiry Learning. *Journal of the Learning*, 22(3), 340–374. <https://doi.org/10.1080/10508406.2012.748664>
- Gnaldi, M., Bacci, S., Kunze, T., & Greiff, S. (2020). Students' Complex Problem Solving Profiles. *Psychometrika*, 85(2), 469–501. <https://doi.org/10.1007/s11336-020-09709-2>
- Greiff, S., Fischer, A., Stadler, M., & Wüstenberg, S. (2015). Assessing complex problem-solving skills with multiple complex systems. *Thinking and Reasoning*, 21(3), 356–382. <https://doi.org/10.1080/13546783.2014.989263>
- Jonassen, D. H. (2011). *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments* (Vol. 19, Issue 5). Routledge, Taylor & Francis Group.
- Kroner, S., Plass, J. L., & Leutner, D. (2005). Intelligence assessment with computer simulations. *Intelligence*, 33, 347–368. <https://doi.org/10.1016/j.intell.2005.03.002>
- Molnar, G., & Csapo, B. (2017). Exploration and learning strategies in an interactive problem-solving environment at the beginning of higher education studies. *Proceedings of 12th Edition of the International Forum on Knowledge Asset Dynamics*, 283–292.
- OECD. (2023). *PISA 2022 Assessment and Analytical Framework*. PISA, OECD Publishing. <https://doi.org/10.1787/dfe0bf9c-en>

- Pamungkas, M. D., & Franita, Y. (2019). Keefektifan Problem Based Learning untuk Meningkatkan Kemampuan Keefektifan problem based learning untuk meningkatkan kemampuan literasi matematis siswa. *Jurnal Penelitian Pendidikan Dan Pengajaran Matematika*, 5(2), 75–80.
- Pamungkas, M. D., Waluya, S. B., Mariani, S., & Isnarto. (2023). A Systematic Review of Complex Problem-Solving in Education and Mathematics Education. *Journal of Higher Education Theory and Practice*, 23(16), 87–101. <https://doi.org/10.33423/jhetp.v23i16.6465>
- Savery, J. R. (2019). Comparative Pedagogical Models of Problem-Based Learning. In *The Wiley Handbook of Problem-Based Learning*. <https://doi.org/10.1002/9781119173243.ch4>
- Schindler, M., & Lilienthal, A. J. (2022). Students' collaborative creative process and its phases in mathematics: an explorative study using dual eye tracking and stimulated recall interviews. *ZDM - Mathematics Education*, 54(1), 163–178. <https://doi.org/10.1007/s11858-022-01327-9>
- Sugiyono. (2016). *Metode Penelitian Kombinasi (Mix Methods)* (Sutopo (ed.)). Alfabeta.
- Wijnia, L., Noordzij, G., Arends, L. R., Rikers, R. M. J. P., & Loyens, S. M. M. (2024). The Effects of Problem-Based, Project-Based, and Case-Based Learning on Students' Motivation: a Meta-Analysis. In *Educational Psychology Review* (Vol. 36, Issue 1). Springer US. <https://doi.org/10.1007/s10648-024-09864-3>
- Wüstenberg, S., Greiff, S., & Funke, J. (2012). Complex problem solving - More than reasoning? *Intelligence*, 40(1), 1–14. <https://doi.org/10.1016/j.intell.2011.11.003>