Southeast Asian Mathematics Education Journal

P-ISSN 2089-4716 | E-ISSN 2721-8546
Vol. 16 No. 1, 2026
DOI
http://dx.doi.org/10.46517/seamej.v16i1.320

Problem-Solving in School Geometry for Prospective Mathematics Teachers

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Abstract

Problem-solving in school geometry is one of the indispensable abilities for prospective mathematics teachers as a provision for their future careers. This research aims to investigate learning and teaching processes on problem-solving in school geometry and its corresponding impact on prospective mathematics teachers' abilities. To investigate this, we conducted a qualitative case study in the form of online classroom observations and their corresponding written assessment for the case of problem-solving in school geometry, involving 47 mathematics education students (20-21 years old) in one of the universities in Indonesia. The results of this study showed that the learning and teaching processes are implemented through the use of a combination of deductive and inductive teaching approaches in which students contribute actively to problem-solving activities. From written student work, we found various solution strategies and conceptual difficulties in solving school geometry problems. We conclude that the use of the deductive and inductive approaches has influenced students' ability and creativity in solving geometry problems. This implies that the combination of the teaching approach has contributed to the development of prospective mathematics teachers' ability in dealing with non-routine geometry problems.

Keywords: Geometry Education, Problem-Solving, Prospective Mathematics Teachers, Teaching and Learning Approaches.

Introduction

One of the abilities needed for the 21st century is problem-solving (Funke et al., 2018; Jamaludin & Hung, 2017). Problem-solving has become a central goal in school mathematics curricula all over the world (e.g., Doorman et al., 2007; Kemdikbud, 2013; National Council of Teachers of Mathematics, 2001; Thompson & Kaur, 2011). Problem-solving ability can be developed in school mathematics through, inter alia, learning geometry topics (Bokosmaty et al., 2015; Erbas et al., 2005). This problem-solving ability, particularly in geometry, is not only important for school students but also for mathematics education students as prospective mathematics teachers for their future life and careers (Jupri & Syaodih, 2016; Jupri, 2017; Koyuncu et al., 2015). Addressing the problem-solving ability of prospective mathematics teachers is therefore important for the future of teacher education (Richmond et al., 2019; Zeichner, 2022).

Previous studies concerning prospective mathematics teachers' problem-solving ability in geometry have, however, shown various results. Koyuncu, Akyuz, and Cakiroglu (2015) found that prospective mathematics teachers prefer to have geometric rather than algebraic solutions in solving plane geometry problems. Prospective mathematics teachers encountered difficulties in dealing with geometry problems related to base concepts (Horzum & Ertekin, 2017) and in dealing with problems related to diagonals of quadrilaterals (Ayvaz et al., 2017). In Indonesia, investigations on prospective mathematics teachers' ability in problem-solving geometry topics, to a limited extent, have been carried out with different focuses. For example, Darminto (2013) found that problem-solving ability is influenced by creativity, while Astuti (2017) emphasized that experience in solving various problems is crucial for further problem-solving activities. Other results have shown that prospective mathematics teachers encountered difficulties in problem-solving related to proving in geometry (Masfingatin et al., 2018) and related to contextual problems (Nasrullah et al., 2019). The results of these studies motivated us to further investigate how Indonesian prospective mathematics teachers engage in problem-solving activities, particularly in the learning and teaching processes of geometry topics. To a certain extent, this are of research is underexplored.

Selected Topics in School Mathematics (STSM) is one of the courses for prospective mathematics teachers in Indonesia. In this course, essential mathematics topics, including school geometry, are addressed to strengthen conceptual understanding, procedural skills, and problem-solving abilities. We wonder how the learning and teaching processes are implemented to strengthen the problem-solving ability of prospective teachers, particularly in the case of geometry topics. Considering this account, this study aims to investigate the implementation of the learning and teaching processes of the STSM course and its corresponding impact on prospective mathematics teachers' ability in problem-solving geometry topics.

To investigate the aim of this study, we use two main theoretical frameworks, including types of teaching and learning approaches and problem-solving. Regarding types of teaching and learning approaches, in general, they can be distinguished into deductive and inductive approaches (Cardino & Cruz, 2020; Prince & Felder, 2006; 2007). In the deductive approach, the teaching and learning process is implemented from general ideas, such as explaining concepts and principles, to more specific ideas, such as giving examples and exercises that apply concepts and principles (Jupri et al., 2021; Prince & Felder, 2006; 2007). In the inductive approach, the teaching and learning process is implemented from more specific ideas, such as exploring problems, to more general ideas of developing concepts and principles from exploring activities (Jupri et al., 2021; Prince & Felder, 2007). The combination of these two teaching approaches means that both characteristics of the approaches appear simultaneously in the teaching and learning processes (Lackner, 1972; Prince & Felder, 2006; 2007).

Concerning problem-solving, in general, it refers to a process of applying acquired knowledge for solving new previously unfamiliar (or non-routine) problems (Doorman et al., 2007; Posamentier & Stepelman, 1990). In the context of geometry, therefore, problem-solving can be described as an activity of applying geometry knowledge to solving non-routine geometry problems. According to Polya (1973), in the general situation and in mathematics, in particular, there are four main stages that should be passed through in a problem-solving process, i.e., understanding the problem, devising a plan, carrying out the plan, and looking back (checking and extending). These four stages can be applied in the teaching and learning process as a kind of teaching strategy or in assessing processes and products of problem-solving (Lam et al., 2011). In this study, the four stages of problem-solving are used for analysing the process and the product of prospective mathematics teachers' written work in solving non-routine geometry problems.

Methods

A qualitative case study in the form of self-observations was conducted to investigate the implementation of teaching and learning processes of the Selected Topics in School Mathematics (STSM) course for the case of problem-solving in school geometry. In the preparation stage, the first author prepared the initial draft of a lesson plan and the tasks for the formative test. The first version of the lesson plan and formative tasks was then reviewed by the second and third authors. Next, based on the review and the discussion among the authors, we revised the plan and formative tasks to obtain ready teaching materials. In this preparation phase, we also decided on how to use a combination of deductive and inductive teaching approaches.

In the second stage, the self-observations of the teaching and learning processes included two parts. In the first part, we observed the teaching and learning processes of two meetings on problem-solving of school geometry for the topics of triangles and quadrilaterals, lasting for 2 x 100 minutes, involving 47 mathematics education students (20-21 year-olds) in one of the state universities in Bandung, Indonesia. In the second part, we observed the results of a formative individual written assessment, which lasted for 30 minutes, on solving non-routine geometry problems. The non-routine geometry problems were taken from a module for pre-service mathematics teachers and from other relevant textbooks containing non-routine geometry tasks (e.g., Aziz & Budi, 2013; Junaedi, 2019; Kurniawan & Suryadi, 2007). In this self-observation, the first author did the teaching, made notes on the teaching activities, analysed written student work, and reflected upon his PowerPoint slides and the additional teaching notes; the second author observed the teaching and learning process; and the third author checked written student work, PowerPoint slides, and pictures of the teaching and learning process. From the two parts of the observations, the data that we collected included field notes of the teaching processes, PowerPoint slides, written student work, and pictures from the meetings.

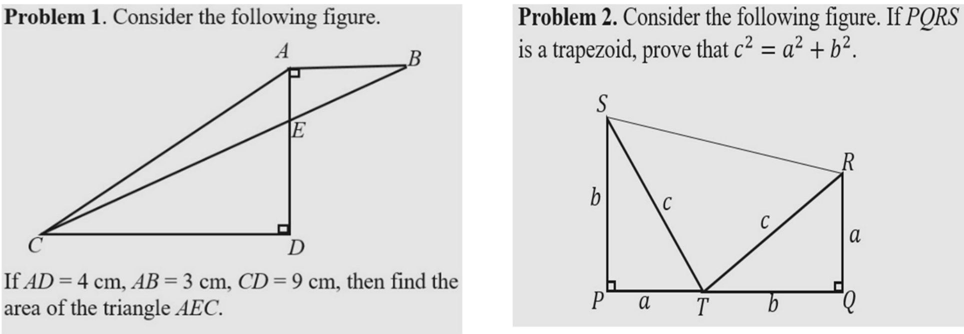
In the third stage, to analyse the data on the teaching and learning processes, we used the framework of types of teaching approaches. To analyse written student work, including problem-solving strategies and difficulties, we used problem-solving stages according to Polya (1973). In this analysis, the second and third authors checked PowerPoint Slides, pictures of the teaching process, and written student work. Initial results of the checking process were then discussed with the first author. Finally, based on the discussion among authors, the final results of the analysis were obtained.

Results and Discussion

To address the results of the investigation of the implementation of the learning and teaching processes and their corresponding impact on prospective mathematics teachers' ability in problem-solving geometry, this section presents the results and discussion of two parts of the self-observations. The first subsection presents the results of the observation on the teaching and learning process on problem-solving of geometry, and the second subsection outlines the results of the analysis of written student work from the formative assessment.

Teaching and Learning Processes on Problem-Solving of Geometry

The teaching and learning processes in the course of Selected Topics for School Mathematics (STSM), for the case of problem-solving in geometry, were started by the lecturer by reminding students about the concepts, properties, and formulas for quadrilaterals and a triangle. Next, the lecturer gave two problems (shown in Figure 1) as examples of how to use the concepts, properties, and formulas of the triangle and quadrilaterals in the problem-solving processes. In terms of Polya (1973), Problem 1, in Figure 1 (a), concerns a problem to find; and Problem 2, in Figure 1(b), concerns a problem to prove.



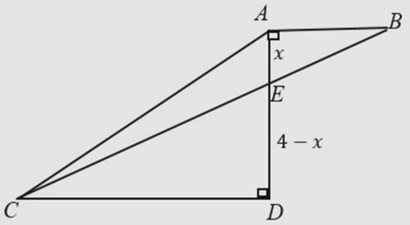
(a) (b)

Figure 1. Two geometry problems in the teaching and learning process: (a) Problem to find; (b) Problem to prove

Before discussing solutions to the two problems above, the lecturer provided time for students to work independently. After waiting for about 10 minutes, the lecturer guided the classroom discussion for the case of Problem 1. The lecturer asked students what the unknown, the condition, and other information given in the problem. Next, he guided the problem-solving process. During the guidance, i.e., for each step of the solution (from understanding the problem, devising a plan of solution, carrying out a solution, and looking back to the solution), the lecturer posed relevant questions to students and would not continue if they did not provide relevant responses. This means that the guidance and explanation processes were combined with the use of a question-and-answer strategy. Figure 2 presents the solution for Problem 1, which is rewritten concisely. A difficult moment for students in this classroom discussion, which took time, occurred when devising a plan, i.e., it was found difficult to come to an idea of the similarity of two triangles for determining the length of *AE*.

For the case of Problem 2, which is classified as a problem to prove, the classroom discussion was initiated by one of the students. The student proposed proof by applying formulas of the area of a triangle and a trapezoid. In the proving process, before applying area formulas, mathematics education students should see that the whole quadrilateral is a trapezoid consisting of three triangles. The proof is rewritten concisely and is presented in Figure 3. After discussing these two problems, the lecturer guided students to draw conclusions about the process of problem-solving that needs more than only a conceptual understanding of geometry concepts. Next, he gave two more problems as a formative individual written assessment. We address the results of this written student work in the next subsection.

Let $AE = x$, which therefore $DE = 4 - x$.



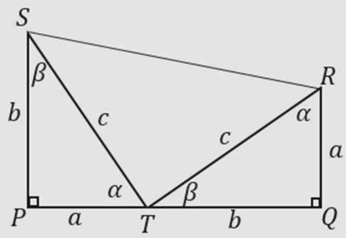
Because $\angle BAE = \angle CDE$, and $\angle AEB = \angle DEC$, then $\Delta AEB \sim \Delta DEC$.
As a consequence, we obtain

$\frac{AE}{DE} = \frac{AB}{DC} = \frac{3}{9} = \frac{1}{3}$.
$\Leftrightarrow \frac{x}{4-x} = \frac{1}{3}$.
$\Leftrightarrow 3x = 4 - x$.
$\Leftrightarrow 4x = 4$.
$\Leftrightarrow x = 1$

Therefore, the area of $\Delta AEC = \frac{1}{2}.AE.CD = \frac{1}{2}.1.9 = \frac{9}{2}$ cm^2.

Figure 2. Solution to Problem 1

Let $\angle PTS = \angle QRT = \alpha$, and $\angle PST = QTR = \beta$.
As a consequence $\angle RTS = 180^\circ - (\alpha + \beta) = 90^\circ$.
This means ΔRTS is a right triangle.



Area PST + Area QTR + Area RTS = Area $PQRS$.

$\Leftrightarrow \frac{1}{2}ab + \frac{1}{2}ab + \frac{1}{2}c^2 = \frac{1}{2}(a+b)(a+b)$.

$\Leftrightarrow ab + ab + c^2 = (a+b)^2$.

$\Leftrightarrow 2ab + c^2 = a^2 + b^2 + 2ab$.

$\Leftrightarrow c^2 = a^2 + b^2$.

Figure 3. Solution to Problem 2

From the description of the findings, we can discuss two main points. First, we can summarize that the sequence of the teaching and learning process is as follows. It starts from reminding the concepts, principles, and formulas of a triangle and quadrilaterals that can be used for problem-solving activities; to giving problems and an opportunity to students to work independently; to guiding classroom discussion, including giving opportunities for students to propose their ideas in problem-solving; and to providing an individual written assessment. Taking this sequence of teaching and learning into consideration, which starts from general ideas of reminding concepts and principles of geometry to provide students opportunities to propose their ideas and guiding classroom discussion as well as the conclusion, we consider that the lecturer uses a combination of deductive and inductive teaching approaches in the teaching and learning process (Jupri et al., 2021; Ndemo et al., 2017; Prince & Felder, 2006; 2007). This means that the teaching and learning process has created a situation in which a balanced active contribution between the students and the lecturer during the problem-solving process.

Second, we noted that even if only expressed verbally during the teaching process, the lecturer guided students in problem-solving activities by implementing four stages of problem-solving according to Polya (1973). In line with other relevant studies (e.g., Bokosmaty et al., 2015; Gulam & Arenas, 2024; Lam et al., 2011), from a pedagogical perspective, this study provides an example of how to use Polya's heuristics of problem-solving in the teaching and learning practice.

Analysis of Written Student Work on Problem Solving of Geometry

The individual written assessment assessed mathematics education students to solve two geometry problems, i.e., Problem 3 and Problem 4 (shown in Figure 4). These problems are considered to be non-routine problems and, in terms of Polya (1973), are classified into problems to find. Problem 3 invites a problem-solving activity that needs the use of quadrilateral and triangle concepts. Problem 4 invites a problem-solving activity that is mainly related to the concept of the area of a triangle. Next, the two problems were addressed in the next meeting of the course.

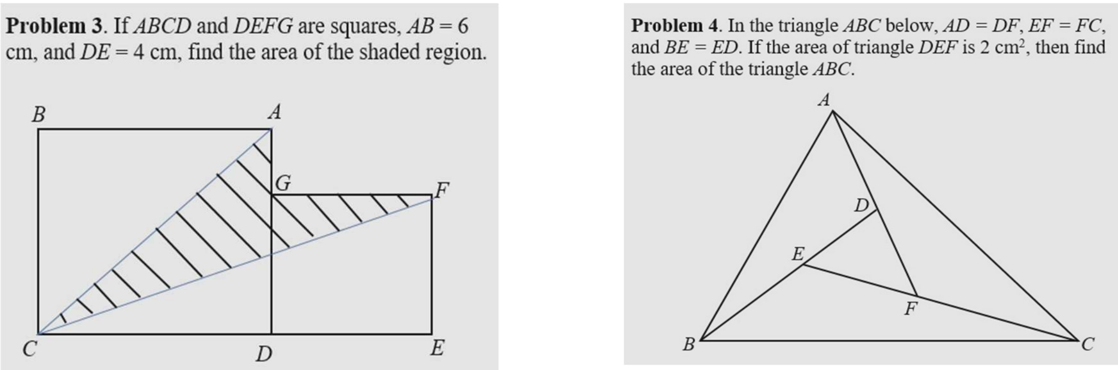
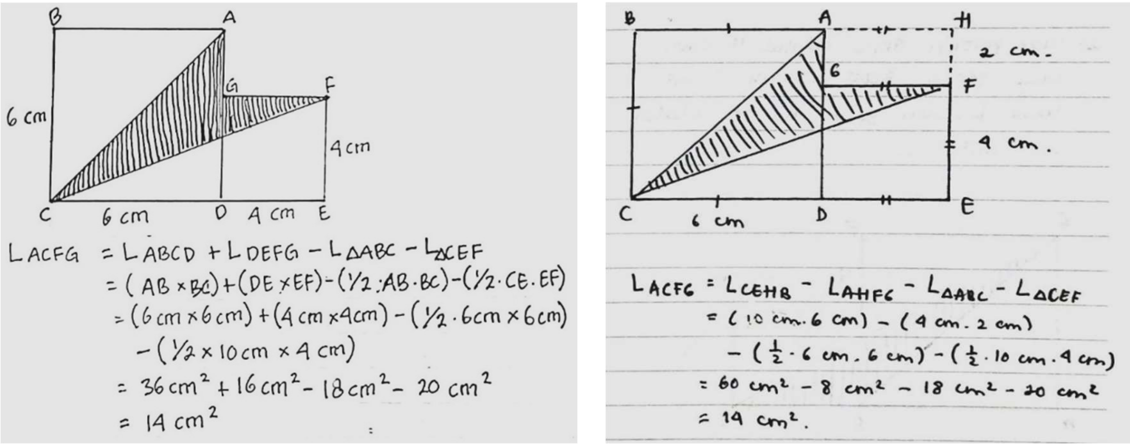


Figure 4. Two geometry problems in the individual written assessment

From the analysis, for the case of Problem 3, we found that 36 out of 47 students solved this problem correctly. This means that the problem is relatively easy for about 76% of the participating students. In addition, we found four different strategies for solving this problem. Two different strategies, i.e., Strategy 1 as the most frequently used (49%) and Strategy 2 as the least frequently used strategy (6%), are shown in Figure 5. In our view, both strategies show creativity in the problem-solving processes. In particular, for the case of Strategy 2, students should construct a rectangle *CEHB*, which is not known previously, to simplify the calculation of the area of the *ACFG*.

Other two different strategies for obtaining the area of *ACFG* are carried out consecutively as follows: (1) adding areas for triangles *AGC* and *FGC*, and (2) using a similarity of two triangles to obtain *K* as the intersection point for *CF* and *GD,* adding areas for triangles *FGK* and *AKC*. These different strategies were discussed in the further meeting of the course. During the discussion, the lecturer asked a representative student for each different strategy to explain it such that other students could learn his/her strategy. Also, during the explanation, the lecturer asked the student to explain in terms of Polya's problem-solving stages verbally. Difficulties encountered by students in solving Problem 3 include finding an appropriate altitude of a triangle for a given corresponding base of the triangle, applying the similarity concept of two triangles, and making careless mistakes in calculation.



(a) (b)

Figure 5. Two different strategies from written work of mathematics education students for solving Problem 3: (a) Strategy 1, and (b) Strategy 2

For the case of solving Problem 4, we found that 9 out of 47 students solved the problem correctly. This means that the problem is relatively difficult for most of the participating students. Even if we observed some different ways of solution processes, we found only one strategy for solving this problem. Figure 6 presents a representative example of written student work showing the solution process of Problem 4. As observed in written student work and revealed during the classroom discussion, the main difficulty for students in solving this problem concerns seeing a common altitude for two triangles having the same length of their bases. For example, a student could not see a common altitude of the two triangles *DEF* and *ADE,* having the same length of bases, namely *AD* = *DF.* As a consequence, the student could not conclude that these two triangles have the same area. Other difficulties include constructing *AE*, *CD*, and *BF;* and finding appropriate geometric concepts to solve the problem. For example, some students tried to use the similarity of triangles to find areas for *ADB* and *CFA* but then failed because of a lack of information on the problem.

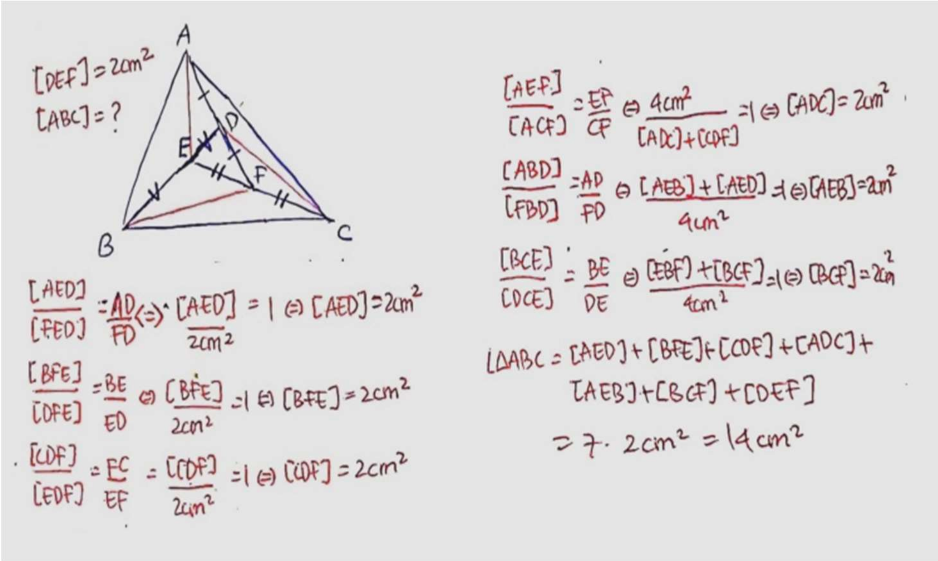


Figure 6. A representative example of written student work for Problem 4

From the description of the findings in this section, we note two points. First, we consider that a problem-solving activity, which is supported by the use of open-ended problems, facilitates the development of creativity. The results of this study are in line with the results of other studies (e.g., Jupri & Syaodih, 2016; Kwon et al., 2006; Szabo et al., 2020) in terms of the emergence of various solution strategies in problem-solving activities. In terms of creativity, the use of different strategies indicates the use of divergent thinking in general and flexible thinking in particular (De Vink et al., 2022; Kwon et al., 2006; Sawada, 1997).

Second, the findings on the difficulties in dealing with geometry problems, for instance, difficulties in seeing the same geometric figures with different perspectives, indicate that mathematics education students need more practice in visual perception, that is, in perceiving and processing visual information by sensory or mental processes (Gal & Linchevski, 2010). Other difficulties, such as translating geometry problems into algebraic models and making mistakes in arithmetical calculations, are in line with previous studies on the difficulties in mathematization processes (De Lange, 2006; Jablonksi, 2024; Jupri et al., 2021).

From the two subsections above, we observed that the teaching and learning process applying Polya's framework, although it was implicit, has influenced mathematics education students' ability in dealing with non-routine problems in geometry. The students independently, confidently, and flexibly were able to solve problems with open-ended characters. The two test problems invited participants' creativity in terms of the use of different solution strategies and visualisation. Therefore, the two parts of observations, i.e., the teaching and learning process and the written individual test, are not separable. They are one unity in the process of analysis.

Conclusion

Based on the description of the findings and discussion in the previous sections, we draw the following three conclusions. First, the teaching and learning process on problem-solving in school geometry for mathematics education students, as prospective mathematics teachers, is implemented by combining deductive and inductive approaches. The teaching process, under the lecturer's guidance, proceeds consecutively from recalling relevant concepts, principles, and formulas of geometry for problem-solving; to exploring given problems by students independently; to conducting classroom discussion, including the provision of opportunities for students to propose their ideas in problem-solving; to administering individual written assessment; and to drawing conclusions based on the whole teaching and learning activities. In our view, recalling relevant knowledge of geometry concerns the use of the deductive approach, while providing opportunities for students to explore and propose ideas in the classroom discussion concerns the use of the inductive approach. This combination has brought the teaching and learning process into student-centered and teacher-centered teaching in a balanced manner. As a reflection of the observations, we note that some students seem to encounter difficulties in applying stages of problem-solving taught verbally by the lecturer in the teaching process. Therefore, to improve the quality of the teaching process in future research, we suggest applying the problem-solving stages explicitly either in the teaching process or in the form of written work during the process of problem-solving.

Second, we conjecture that the use of the combination of the deductive and inductive approaches, in which the inductive characters are quite dominant, has influenced students' creativity, particularly in the case of solving geometry problems having open-ended characters. This can be observed from the findings of various strategies for solving the problems, which shows flexibility in thinking and in solving visual geometry problems. For further research, we recommend doing an in-depth investigation on the use of open-ended geometry problems toward students' creative ability, not only on the aspect of flexibility but also on other aspects, including fluency and originality.

Third, the difficulties encountered by students in dealing with geometry problems include perceiving and processing visual information by visual or mental processes, translating geometry problems into algebraic models, and making careless mistakes in arithmetical calculations. These difficulties probably can be reduced by giving students more experiences in problem-solving, such as by providing students with independent or group assignments on problem-solving. In this way, the process of problem-solving activity occurs not only at the teaching and learning processes in classroom situations but also at the students' homes as independent or group learners.

Despite the above conclusions, we acknowledge that this study has some limitations. As the written assessment did not require students to write explicitly their solution process according to Polya's stages, we could not trace explicitly in which stages they really encountered difficulties in problem-solving. Also, as the observations depend only on the aforementioned collected data—including field notes, PowerPoint slides, pictures of the teaching and learning processes, and written student work—to a limited extent, some unclear written work needs further clarification. Therefore, interview data seem necessary to fill this gap if further study will be conducted in the future.

Acknowledgements

This research was funded by the Faculty of Mathematics and Science Education, *Universitas Pendidikan Indonesia*, through the research scheme: *Penelitian Pembinaan dan Pengembangan Research Group* year 2021. We thank mathematics education students for their active participation.

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