Jurnal Elemen, 10(3), 533-545, September 2024
https:/doi.org/10.29408/jel.v10i3.25607

e- ISSN: 2442 - 4226

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Investigating preservice secondary mathematics teachers' skills in posing realistic mathematics tasks

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Abstract

Mathematics tasks situated in realistic situations play a central role in developing and applying mathematical knowledge. However, mathematics educators face difficulties in designing realistic mathematics tasks. This study was conducted to gain deeper insights into the characteristics of mathematical problems that underprepared preservice secondary mathematics teachers pose. This study examined 32 preservice secondary mathematics teachers' problem-posing skills based on three problem-posing situations: structured problem-posing, semi-structured problem-posing, and free problem-posing. As the context of the participants, they did not have learning experiences in designing realistic mathematics tasks. In evaluating the preservice teachers' works, the researchers used several evaluation criteria, namely the compatibility of the problem with the mathematical principles, plausibility and sufficiency of information, the problem text, level of context authenticity, cognitive demand, and the correctness of the solution. The results revealed that most preservice teachers posed problems with the first-order level of context use and low cognitive demand. Additionally, many of them encountered difficulties when attempting to solve the problem. The findings of this study were expected to serve as a basis for developing a curriculum for pedagogic and mathematics courses in teacher education.

Keywords: preservice mathematics teachers; problem posing; realistic mathematics tasks

How to cite: Rianasari, V. F., & Guzon, A. F. H. (2024). Investigating preservice secondary mathematics teachers' skills in posing realistic mathematics tasks. *Jurnal Elemen*, *10*(3), 533-545. https://doi.org/10.29408/jel.v10i3.25607

Received: 25 March 2024 | Revised: 2 July 2024
Accepted: 6 August 2024 | Published: 14 September 2024

Introduction

Mathematics education has traditionally focused on problem-solving skills and the ability to find solutions to given mathematical tasks (Li & Schoenfeld, 2019). However, the dynamic nature of the 21st-century classroom demands a shift in perspective, urging educators to cultivate a deeper understanding of mathematics through problem-posing. Problem posing is the process of constructing interpretations of a concrete situation to formulate meaningful mathematical problems based on a student's previous knowledge and experience (Stoyanova & Ellerton, 1996). Stoyanova and Ellerton (1996) identified three different categories of problem-posing situations. Those are free situations, semi-structured situations, and structured situations. In free situations, students are simply asked to pose a problem without restrictions. In semi-structured situations, students are given an open situation and asked to investigate it using their previous mathematical knowledge and experiences (Stoyanova & Ellerton, 1996). In structured situations, students are invited to generate new problems by reformulating the problems that have been solved or by adjusting the conditions, assumptions, or questions of given situations (Stoyanova & Ellerton, 1996). Teachers' ability to pose high-quality mathematics tasks is essential for effective mathematics teaching and learning (Crespo & Harper, 2020). Particularly for preservice teachers, engaging in problem-posing activities not only enhances their mathematical thinking but also lays a strong foundation for effective teaching practices (Silber & Cai, 2021).

The ability to design mathematics tasks that link mathematical knowledge to real-life situations is crucial for preservice teachers. In Realistic Mathematics Education (RME), the use of contextual or realistic tasks in mathematics teaching and learning is rooted in Freudenthal's idea that views mathematics as a human activity rather than just a subject to be taught (Freudenthal, 1991). In RME, tasks situated in realistic situations serve as a source for developing mathematical concepts and procedures and applying mathematical knowledge (van den Heuvel-Panhuizen & Drijvers, 2020).

Realistic mathematics tasks bridge the gap between abstract concepts and their application in daily life. Promoting the skills to design mathematics tasks that align with real-world contexts enables preservice teachers to empower their future students to relate mathematical concepts to their experiences and make the subject more relevant and meaningful. Moreover, through the practice of realistic problem-posing, preservice teachers can gain a deeper insight into the connections between mathematical concepts and the world around them (Hartmann et al., 2021; van den Heuvel-Panhuizen, 2005). They gain the ability to recognize mathematical opportunities in real-life situations, which is vital for fostering students' mathematical literacy and equipping them for the challenges of the future (Wijaya et al., 2018).

However, many preservice teachers are not yet adequately equipped to design realistic mathematics tasks. Investigating their skills in posing realistic mathematics tasks helps identify areas where they may lack understanding or proficiency. Numerous studies have investigated problem-posing in relation to real-world situations. Some of these focus on the use of real-life artifacts as sources for problem-posing (Bonotto, 2013; Chen et al., 2011, 2015), while others examine teachers' realistic problem-solving and problem-posing (Chen et al., 2011).

Additionally, there are studies that integrate mathematical modeling with problem-posing (Chan, 2013; Downton, 2013; Hartmann et al., 2021; Lee, 2013). However, these studies have not specifically addressed the challenges faced by preservice teachers in designing realistic mathematics tasks. Identifying these challenges can inform targeted interventions and support during their teacher education program, ensuring that preservice teachers build a solid foundation to teach mathematics effectively. Moreover, investigating preservice teachers' skills in this area allows for targeted professional development and support to enhance their instructional practices. By improving their ability to pose realistic tasks, preservice teachers can provide more engaging and meaningful mathematics instruction to their future students.

Methods

Research design

The main goal of this study was to examine the preservice secondary mathematics teachers' skills in designing realistic mathematics tasks. The research methodology employed in this study was a survey, utilizing a descriptive model that focuses on describing situations without interfering with the situations. This study was designed to seek the answers to the research question by employing descriptive quantitative techniques.

Participants

The participants in this study were preservice teachers at a private university in Indonesia. Thirty-two third-year preservice teachers, comprising 5 males and 28 females, enrolled in a compulsory three-credit course and volunteered to participate in the study. The course aims to equip preservice teachers with the competence to design learning activities for high school mathematics curriculum. During the course, the researcher administered a take-home test to examine their skills in posing realistic mathematics tasks. However, prior to the data collection, the preservice teachers had limited exposure to hands-on learning activities that prepared them for designing such tasks.

Problem posing tasks

This study examined preservice secondary mathematics teachers' problem-posing skills based on three problem-posing situations as proposed by Stoyanova & Ellerton (1996). These situations encompass structured, semi-structured, and free problem-posing. The purpose of utilizing different problem-posing situations was to examine preservice teachers' competencies in designing realistic mathematics tasks within each problem-posing situation. Additionally, the mathematical content of the tasks aligns with the topics of high school mathematics. The problem-posing tasks were formulated into a take-home test, which the preservice teachers were required to complete and submit within three days.

Structured problem posing situation

For the initial problem-posing task, the preservice teachers were presented with one task (Task A) that was adapted from Moore (2012). The participants were asked to reformulate it into a new realistic mathematics task. Task A is presented in Figure 1.

<u>Task A</u>

Reformulate the following problem and create a new mathematics problem!

Consider a Ferris wheel with a radius of 15 meters that takes 80 seconds to complete a full rotation. The distance of the center of the Ferris wheel to the ground is 17 meters. If someone boards the Ferris wheel at the bottom and begins a continuous ride on it, how long will it take the person to reach a height of 12 meters?

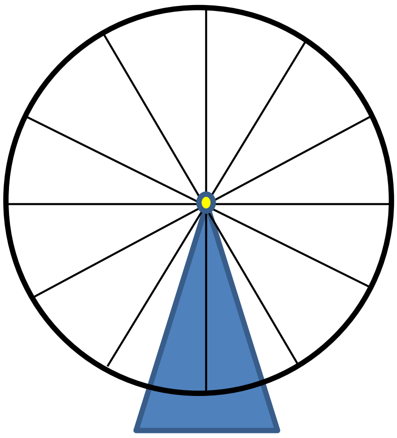

Figure 1. Task A (structured problem posing)

In this structured problem posing, preservice teachers were asked to stick to the same mathematical content given in the task. They were also asked to provide a solution to their posed task.

Semi-structured problem posing situation

Within the semi-structured problem-posing situation, preservice teachers were asked to design a mathematics task from the given context (Task B) for high school students. The context was adapted from Rosen (2019). Task B is presented in Figure 2.

<u>Task B</u>

Write a realistic mathematics task for the high school level related to the conditions given below!

In a high school, there are 7 female teachers and 9 male teachers. To form the graduation committee, 5 teachers will be appointed as the committee.

Figure 2. Task B (semi-structured problem posing)

Free problem posing situation

In the free problem-posing situation, preservice teachers were instructed to design one realistic mathematics task by using their chosen context. They were explicitly prohibited from plagiarizing existing tasks and required to generate an original task. However, they were permitted to draw inspiration from various sources such as school textbooks, the internet, previous learning experiences, personal encounters in everyday life, and others. They were also required to provide an explanation in their worksheet detailing the sources that inspired their task. Task C is presented in Figure 3.

Task C
Create one mathematics problem based on the context of everyday life that is appropriate for high school students.

Figure 3. Task C (free problem posing)

Data analysis

Each written response by preservice teachers was first assessed based on whether the task was compatible with the mathematical principle and plausible. If the task was suitable to mathematical principles and plausible, then the task was further assessed based on several characteristics of a realistic mathematics task. The basis for these characteristics was the consideration that realistic mathematics tasks should provide students with opportunities to experience progressive mathematization. Therefore, the task should have authentic context, require students to demonstrate that they can deal with a diverse range of cognitive demands, help students to construct a situation model, and foster students' ability to find the missing information or make assumptions. Moreover, the researchers also assessed the quality of the preservice teachers' solutions to their designed tasks. Those evaluation criteria are presented in **Error! Reference source not found.** below.

Table 1. Evaluation criteria of the tasks posed by preservice teachers

Evaluation criteria	Description
The compatibility of the problem with the mathematical principles (Bonotto, 2013; Şengül & Katranci, 2015)	The problem is unsuitable for mathematical principles (non-mathematical problems). The problem is relatively suitable to mathematical principles. The problem is suitable for mathematical principles.
Plausibility and sufficiency of information (Bonotto, 2013)	The problem cannot be solved (implausible problem) Initially plausible mathematical problems, however, with insufficient information Plausible mathematical problems with sufficient information
Problem Texts (Şengül & Katranci, 2015)	The problem text is not understandable. The problem text is relatively understandable. The problem text is understandable.
Level of context authenticity (Salgado, 2016)	Zero-order First-order Second-order
Cognitive demand (Brookhart, 2010)	Lower order thinking skills (remembering, understanding) Lower-order thinking skills (applying) Higher-order thinking skills (analyzing, evaluating, creating)

Evaluation criteria	Description
Type of information (Wijaya et al., 2015)	Task with matched information Task with missing information/superfluous information
The correctness of solution steps (Hartmann et al., 2021)	No steps are correct Only the mathematical model is correct. The mathematical model and mathematical result are correct. The mathematical model, mathematical result, and interpretation are correct.

Results

The compatibility of the problem with mathematical principles

Table 2 shows the proportion of mathematical problems that are compatible with the mathematical principles for each problem-posing situation. For Task C, the researchers found that six responses were not original work, as they were identified through a plagiarism check using Google Docs, indicating that they had been copied from other resources. Therefore, the researchers only analyze the responses from 26 students.

Overall, most of the problems the preservice teachers posed were mathematical problems. Tasks most frequently categorized as relatively suitable with the mathematical principle were tasks within structured problem-posing situations. Of the 32 responses provided, 7 mathematical problems posed by preservice teachers were relatively suitable to mathematical principles. The tasks within this category align reasonably well with mathematical principles. While not perfectly aligned, it involves aspects of mathematics such as quantitative reasoning or logical problem-solving.

Table 2. The proportion of mathematical problems according to the compatibility with the mathematical principles per task

Task	Not suitable	Relatively suitable	Suitable
Task A (structured)	0%	21.88%	78.12%
Task B (semi-structured)	0%	6.25%	93.75%
Task C (free)	0%	3.85%	96.15%

The plausibility and sufficiency of information

Table 3 presents the proportion of responses to each problem-solving situation that was plausible and had sufficient information. Once again, significant variation was observed in the responses to Task A within structured problem-posing situations. Specifically, out of the total 32 problems, 5 problems (15.63%) were implausible, 5 problems (9.37%) were initially plausible with insufficient information, and 24 problems (75%) were plausible with sufficient information. Across all three problem-posing situations, nearly all students (93.75%) were capable of formulating plausible problems with sufficient information within semi-structured problem-posing. Furthermore, the prevailing reason for the lack of plausibility in mathematical problems posed by preservice teachers was attributed to the insufficiency of information.

Table 3. The proportion of plausible mathematical problems according to the plausibility and sufficiency of information per task

Task	Implausible problem	Initially plausible problems with insufficient information	Plausible problem with sufficient information
Task A (structured)	15.63%	9.37%	75%
Task B (semi-structured)	3.125%	3.125%	93.75%
Task C (free)	0	11.54%	88.46%

The problem texts

Table 4 illustrates the percentages of responses that have understandable texts in each problem-posing task. While most of the problems posed within each problem-posing situation were understandable, a considerable number of relatively understandable problems existed. The analysis of the problem texts revealed that the primary factor contributing to this issue was the presence of grammatical errors in Indonesian (as the problems were written in Bahasa Indonesia). Additionally, some preservice teachers encountered difficulties in effectively and efficiently depicting the contexts through their sentences. Consequently, these challenges resulted in the composition of lengthy or ambiguous sentences when describing the given or the chosen contexts.

Table 4. The proportion of mathematical problems according to the problem text per task

Task	Not understandable	Relatively understandable	Understandable
Task A (structured)	12.5%	25%	62.5%
Task B (semi-structured)	3.125%	18.75%	78.125%
Task C (free)	0%	26.92%	73.08%

The level of context authenticity

Table 5 presents the percentage of mathematical problems across different problem-posing situations that exhibited authentic contexts. Mathematics tasks situated in authentic contexts should engage students in applying mathematical principles in a way students might use in real life, and the contexts should motivate students to solve the problem (Stacey, 2015). The levels of authenticity classification for the context of mathematical problems were established by Salgado (2016). He made the classification to analyze how context influences the formulation of a mathematical model and the interpretation of its solution. The three distinct levels of contexts were zero-order, first-order, and second-order. At the zero-order level, the context provides explicit instructions that allow direct actions or inferences in solving a mathematics problem. However, this level does not involve the interpretation of mathematical results or arguments. At the first-order level, the context is used to identify or select relevant information, variables, or relationships to formulate the mathematical problem. Additionally, the context is employed to evaluate the appropriateness of the obtained mathematical results. The second-order level of context serves as a source for defining or retrieving pertinent variables, relationships, or assumptions required for the mathematical formulation of a problem.

Moreover, the context is employed to assess the adequacy of the mathematical results or arguments in relation to the original problem.

A significant proportion of the problem instances generated by preservice teachers were classified as having a first-order level of contextualization. Furthermore, a considerable number of problems fell into the zero-order level of context category, particularly in the case of free problem posing, where preservice teachers were given the autonomy to select their own context. These findings suggest that the preservice teachers encountered challenges in designing a meaningful context that effectively leveraged students' everyday reasoning to address the problem.

Table 5. The proportion of mathematical problems according to the authenticity of the context per task

Task	Zero-order	First-order	Second-order
Task A (structured)	12.5%	59.38%	28.12%
Task B (semi-structured)	3.125%	78.125%	18.75%
Task C (free)	19.23%	65.38%	15.39%

An example of a task with the context within the first-order level is presented in Figure 4.

> The youth organization in Balarama village is set to appoint 5 new core committee members for the positions of chairperson, vice-chairperson 1, vice-chairperson 2, secretary, and treasurer. There are 7 women and 9 men who have put themselves forward for these positions. Given that the chairperson and vice-chairperson 1 must be men, and vice-chairperson 2 must be a woman, determine the number of possible ways to form the new committee.

Figure 4. Task with the first-order level of context

Type of information

Table 6 shows the proportion of mathematical tasks categorized by the type of information provided. Tasks within structured problem posing (Task A) have predominantly missing information, meaning that not all the information needed is provided. Furthermore, tasks within semi-structured problem posing (Task B) contain mostly matched information, meaning that all required data are directly given in the tasks. Tasks within free problem posing (Task C) also show a high amount of missing information. Notably, none of the tasks contain superfluous information.

Table 6. The proportion of mathematical problems according to the type of information

Task	Matched information	Missing information	Superfluos information
Task A (structured)	12.5%	87.5%	0%
Task B (semi-structured)	71.9%	28.1%	0%
Task C (free)	15.6%	84.4%	0%

An example of a task with matched information is presented in Figure 5 and an example of a task with missing information is presented in Figure 4.

> A ship sails 120 km east, then changes its course by 60° and continues for 100 km until it stops. The distance from the initial sailing point to the stopping point is...

Figure 5. Task with matched information

The cognitive demand

Table 7 shows the proportion of responses across different cognitive demands, as proposed by Brookhart (2010). The results demonstrate that the majority of problems posed by preservice teachers were tasks that only required students to apply mathematical principles they had learned, as shown in Figure 5. For the higher-level thinking category, task A within structured problem posing, which originally presented preservice teachers with a problem requiring a higher-order thinking level, yielded the highest percentage of responses demanding higher cognitive demands compared to the other tasks. An example of a task that requires students to perform higher-order thinking skills is presented in Figure 6.

Table 7. The proportion of mathematical problems according to cognitive demand per task

Task	Remembering, Understanding	Applying	Analyzing, Evaluating, Creating
Task A (structured)	12.5%	46.88%	40.62%
Task B (semi-structured)	3.125%	65.625%	31.25%
Task C (free)	7.69%	69.23%	23.08%

Lisa is about to ride a Ferris wheel with its highest point reaching 42 meters above the ground, and its lowest point 2 meters above the ground. The Ferris wheel takes 120 seconds to complete one full rotation, assuming the rotation is constant. What will be Lisa's height above the ground after riding the Ferris wheel for 150 seconds?

Figure 5. Task with matched information

The correctness of solution steps

Table 7 shows the percentages of mathematical problems posed by preservice teachers according to the correctness of solution steps. The majority of responses for tasks B and C have correct solution steps. However, most of the students had difficulties solving the problems they posed within structured problem posing.

Table 8. The proportion of mathematical problems according to the correctness of solution steps per task

Task	No steps are correct	Only the mathematical model is correct	Only the mathematical model and mathematical result are correct	All steps are correct
Task A (structured)	31.25%	21.875%	9.375	37.5
Task B (semi-structured)	3.125%	9.375%	6.25%	81.25%
Task C (free)	0%	11.54%	26.92%	61.54%

Discussion

The results shown in tables 2-7 demonstrate the characteristics of mathematics problems posed by preservice mathematics teachers who lack experience in designing mathematics tasks situated in daily life contexts. The findings show that underprepared preservice mathematics teachers are capable of posing problems that are compatible with the mathematical principle, formulating plausible problems with sufficient information, and having understandable texts. Moreover, although the majority of the problems were solvable, the preservice teachers had difficulties in providing correct solution steps for Task A (reformulating the problem about the Ferris wheel). This finding might indicate that the preservice teachers might not have a good understanding of the topic presented in the problem about the Ferris wheel. Moreover, the problem presented by the researchers in task A was not typical of mathematics textbooks' problems. This might lead to difficulties for the preservice teachers in either solving or reformulating the problem.

The findings also revealed that the preservice teachers were struggling to pose problems with authentic context. The majority of the problems posed by preservice teachers featured camouflage contexts. Solving problems with camouflage contexts does not require daily life experience or common-sense reasoning (Wijaya et al., 2015). Additionally, the preservice teachers faced difficulties posing problems requiring higher-order thinking skills. These two findings are interrelated, as a task with an authentic context should portray a real-world problem without ready-made algorithms to solve the problem (Kramarski et al., 2002). Consequently, mathematics tasks with authentic contexts typically demand students to engage in cognitive processes beyond the application. These findings align with several other studies that examined the abilities of preservice mathematics teachers in designing realistic mathematics problems (Kohar et al., 2019; Siswono et al., 2018).

The findings of this study suggest that the difficulties encountered by preservice teachers in designing mathematics tasks with authentic contexts that demand high-level thinking skills may be related to their limited exposure to such problems during their mathematics education in schools. Mathematics learning in schools, especially in Indonesia, is often characterized by an emphasis on memorization and routine problem-solving exercises. With this traditional approach, students have little opportunity to develop their abilities in solving non-routine mathematical problems, especially those related to everyday life contexts. This results in preservice teachers having insufficient knowledge and experience to design realistic mathematics problems. Therefore, it is crucial to equip preservice teachers with the knowledge and experience necessary for designing realistic mathematics tasks.

In response to the lack of skills among preservice teachers in designing realistic mathematics problems, the researchers proposed several ideas that could be accommodated to provide meaningful experiences for preservice teachers in designing realistic mathematics problems. First, exposing students to realistic mathematical problems can help them develop problem-solving skills and help them see how mathematical problems can connect the world of mathematics with students' everyday lives (Stacey, 2015). Second, involving preservice teachers in collaborative problem-design activities can help them exchange ideas and provide feedback to each other in designing problems. Therefore, collaboration in designing mathematical problems can encourage creativity and enrich them with diverse perspectives (Crespo & Harper, 2020). Third, providing preservice teachers with experiences to reflect on the problems they have designed and receiving feedback from peers and instructors can help them improve the quality of the problems they have designed (Olteanu, 2017; Sevinc & Lesh, 2021). Lastly, providing professional development programs, such as workshops and seminars, can help them improve their competence in designing realistic mathematics problems. By implementing these strategies, researchers and educators can provide preservice teachers with meaningful learning experiences that equip them with the skills and knowledge needed to design realistic mathematics tasks for their future students.

Conclusion

This study reveals that preservice teachers experience difficulty in designing realistic mathematics tasks. However, their work indicates that they have the potential to propose realistic mathematics tasks if given the opportunity and guidance in designing them. Analysis of the responses in each problem submission situation indicates that most preservice teachers propose problems with a first-order level of context use and low cognitive demand. Furthermore, most responses, particularly in task A, suggest that preservice teachers encounter difficulties when solving their proposed problems. These findings underscore the need for teacher education programs to provide additional support and training to help preservice teachers develop a deeper understanding of mathematical concepts and enhance their skills in solving and designing mathematics tasks, particularly those situated in everyday life contexts.

There are two limitations of the study. Firstly, this study only focuses on a specific cohort of preservice teachers, which may not reflect the experiences of all preservice teachers. Secondly, the emphasis on particular topics of mathematics and types of tasks may not capture the full range of challenges encountered by preservice teachers in designing realistic mathematics tasks. Future research should consider a broader range of participants and explore a more diverse set of task types to provide a more comprehensive understanding of these challenges.

Acknowledgment

The authors would like to express our gratitude to all participants for their time and willingness to participate in this research.

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.

Funding Statement

The authors would like to thank the United Board for supporting and funding this research.

Author Contributions

Veronika Fitri Rianasari: Conceptualization, writing - original draft, editing, visualization, formal analysis, and methodology; **Angela Fatima H. Guzon:** Validation and monitoring.

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