Preservice physics teachers' nonroutine problem-posing process: Metacognitive strategies and beliefs

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Integrating problem-posing activities into instruction fosters students' critical and creative thinking while deepening their understanding of problem solving. However, complementing the problem-solving process with direct mental processes such as recalling memorized information will make a limited contribution to meaningful learning. In this context, having students construct their own problems and use metacognitive strategies while doing so will increase their cognitive awareness in the problem-solving process. Drawing on this perspective, the present study investigates the processes through which preservice physics teachers pose nonroutine physics problems, focusing on the metacognitive strategies they employ and the pedagogical beliefs they hold during these processes. The study was conducted with 20 volunteer preservice physics teachers from different grade levels at a public university. Data were collected through a five-item problem-posing task, a metacognition-oriented reflection form, and a process-based opinion form, and were analyzed qualitatively. The findings indicated that nonroutine problem-posing performance generally increased with grade level and that preservice physics teachers actively used metacognitive strategies such as ease of learning, decision making about learning, experiencing a sense of knowing, and confidence in the answer during the problem-posing process. Nevertheless, participants faced difficulties, particularly in evaluating alternative solutions and engaging in creative thinking. Despite these challenges, they maintained a positive attitude toward problem-posing activities, highlighting the potential of nonroutine problem posing as an effective pedagogical tool in physics teacher education.

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I. INTRODUCTION

A foundational understanding of physics is essential for individuals to make sense of the events and challenges encountered in daily life. Physics education equips learners with the ability to interpret physical phenomena and to apply fundamental principles and concepts in doing so. This educational process entails presenting physical laws and concepts within a coherent theoretical framework, providing opportunities for experimental application, and fostering the development of effective physics problem-solving skills. It also aims to cultivate students' critical thinking, creative problem-solving abilities, and scientific ways of understanding the physical world. Given that higher-order cognitive skills—such as critical thinking and problem solving—are recognized as key competencies for contemporary citizenship, developing these skills is vital for all individuals [1]. However, it is a frustrating reality that some students perform mathematical calculations by memorizing formulas without understanding the concepts [1]. This situation negatively affects the problem-solving process in physics [2]. Approaching a given problem without truly understanding it, using rote methods, does not mean that the problem-solving process has been experienced cognitively in depth, even if the correct result is obtained. From a pedagogical perspective, physics education uses some methods to eliminate these shortcomings and prevent rote learning approaches. For example, active learning strategies that enable students to discover knowledge have been shown to be effective [3]. As is well known, active learning requires the student to participate directly in the process and complete a learning task. In this context, studies have also shown that problem-posing activities contribute to both active learning (direct involvement in the process) and students' success in problem solving [4–6]. In summary, problem-posing holds an important place in education as a pedagogical tool. Mestre emphasized the importance of this approach in education as a result of his study conducted with university students who had taken a mechanics course and made a

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number of recommendations for its use as a pedagogical tool [7].

In this study, the findings regarding how and to what extent preservice physics teachers use metacognitive strategies in the process of posing physics problems are directly related to the quality of future physics education. In this context, systematically supporting preservice physics teachers' problem-posing experience and metacognitive skills has become quite important.

II. THEORETICAL BACKGROUND

A. Problem solving, problem posing, and active learning in physics education

Problem solving is a fundamental competency that influences nearly every domain of daily and professional life. Accordingly, a broad body of research has examined the use of instructional strategies aimed at fostering this skill across diverse disciplinary contexts [8–14]. Whether in blended sports education, artificial intelligence-supported learning environments, or graduate-level instruction, these studies consistently highlight approaches designed to enhance learners' problem-solving abilities for both academic achievement and professional development. Importantly, problem solving is not limited to producing a correct answer; it represents a multifaceted cognitive process that involves exploration, interpretation, strategic planning, and creative thinking.

The roots of research on problem solving in physics lie in the field of cognitive science [15]. Metacognitive processes—such as conceptually structuring a physics problem, choosing appropriate strategies, monitoring the solution, and reorganizing it when necessary—distinguish expert physics problem solvers from novices [16,17]. Problem solving holds an important place in physics courses [18,19]. In the problem-solving process, which is one of the active learning approaches in physics, students are generally directed to solve problems that involve mathematical and verbal expressions of real physical phenomena [20]. The quantitative reasoning activity in "*The Physics Active Learning Guide*," developed by Etkina and Van Heuvelen, provides students with problems that they can solve not only in class but also at home for review or as homework assignments [21]. The same study also uses a problem-posing approach, which involves transforming a real-world physics phenomenon into a physics problem using an effective scenario, as another activity to encourage active student learning. Both problem-solving and problem-posing processes are conducive to student learning. Furthermore, students' problem-solving skills are closely linked to their problem-posing skills [22,23]. Student-centered approaches that require critical thinking and creativity, such as problem solving [24] and problem posing [25], contribute to the development of both students' cognitive skills and metacognitive awareness. In learning environments that incorporate these approaches, students engage in active learning by thinking about decisions related to learning—such as what they will learn, how they will approach learning tasks, what strategies they will use, and what resources they will need—and by actively participating in the process. As Chickering and Gamson emphasize, knowledge is not merely transferred but actively constructed through a process of making conscious decisions about learning [26]. In this context, active learning supports the development of students' metacognitive thinking skills because it encourages students to consciously use their cognitive resources, monitor their understanding, and adapt their learning strategies when necessary. Considering the critical role of metacognitive processes in physics learning environments, it is important to examine the concept of metacognition in physics learning and teaching in greater detail.

B. Metacognition and physics education

A review of the literature shows that the concept of metacognition is associated with individuals' thinking activities about their own thinking. These activities include actions performed in one's mind, such as managing one's own knowledge, skills, and strategies [24]. According to Flavell, who first introduced the concept of "metacognition," it refers to an individual's knowledge about their own cognitive processes and the use of this knowledge to monitor those processes [27]. Flavell modeled metacognition as consisting of metacognitive knowledge and metacognitive experiences, thereby referring to an individual's awareness of their own thinking and learning. This awareness includes topics such as how the person learns and processes information, the strategies they develop during the learning task, and when to use these strategies.

In studies conducted in the field of educational psychology focused on metacognition, the concept of metacognition has been addressed in terms of learning level, learner self-regulation, and the development of learning [28]. Similarly, in physics education, metacognition has become an important area of research in terms of students' in-depth understanding of physics concepts, regulating their own learning, developing problem-solving skills, solving physics problems, and increasing their success and motivation [29–33]. For example, Dulger and Ogan-Bekiroglu, in their studies investigating how students use metacognition when solving physics problems, found that knowledge and monitoring are crucial for producing successful solutions, especially in complex tasks [29].

III. PURPOSE AND IMPORTANCE OF THE STUDY

In physics education, learning concepts only at a superficial level may hinder students from understanding topics in depth. Therefore, it is crucial for students to move away from rote-based solutions and engage with unconventional and thought-provoking problems. Such nonroutine

problems not only develop students' analytical thinking skills but also encourage them to effectively use metacognitive strategies. Preservice physics teachers possessing the ability to create such unconventional problems will contribute to their becoming effective and qualified teachers in their professional lives. Teachers with this ability can increase their students' problem-solving and critical thinking capacities. However, research on the factors influencing problem-posing skills and the metacognitive strategies employed in this process in physics teacher education programs is quite limited. This study aims to address this gap and contribute to the literature. By doing so, it is expected to provide valuable insights into how metacognitive thinking can be fostered through active learning approaches in physics teacher education.

IV. RESEARCH QUESTIONS

The primary objective of this study is to explore preservice physics teachers' ability to pose nonroutine physics problems, the metacognitive strategies they employ during this process, and their perceptions about the process. In this context, the study addresses the following research questions:

RQ1: What is the level of preservice physics teachers' nonroutine physics problem-posing skills?

RQ2: How do preservice physics teachers' problem-posing skills vary across grade levels?

RQ3: What metacognitive strategies do preservice physics teachers employ when posing nonroutine physics problems?

RQ4: What are preservice physics teachers' perceptions and beliefs regarding the impact of posing nonroutine physics problems on physics instruction?

V. RESEARCH METHODOLOGY

A. General background

In this study, a cross-sectional developmental research design was employed. This method examines groups of different ages, experiences, and educational levels simultaneously. Thus, developmental characteristics can be determined without being limited to a single group, saving time. In the study, a nonroutine problem-posing activity was administered to preservice physics teachers at different grade levels, and the metacognitive strategies they used during the activity were analyzed and evaluated. In addition, the participants' perceptions of problem-posing approaches for future physics teaching practices were explored. Details regarding the sample group determined in line with the research design are presented below.

B. Participants

The study sample consisted of first-, second-, third-, and fourth-year students studying in the physics education department at a state university. For this study, which employed a qualitative research design, maximum variation sampling—a purposive sampling technique—was used [34]. To enhance the quality of the research data, sample selection was completed in two stages. In this context, in the first stage, a total of 40 participants were determined by randomly selecting 10 preservice physics teachers from each grade to ensure maximum variation. Each group was coded as A, B, C, or D according to grade level. Each group was provided with an online briefing (10–15 min) about the purpose and stages of the study. This procedure aimed to obtain a more informed and motivated sample of volunteers who were familiar with the research process and able to sustain engagement throughout the study.

After the briefing, in the second phase, participants who voluntarily agreed to take part in the study were identified. Because the study aimed to ensure comparability with an equal number of participants from each grade level and to obtain in-depth data, not all volunteers were included; the sample was limited to 20 participants. A total of 20 prospective teachers, 5 from each grade level, were selected randomly from among the volunteers. This random selection method was employed to minimize bias and maintain the transparency and reliability of the process.

C. Instrument and procedures

Prior to the nonroutine physics problem-posing activity, approximately 30-min online sessions were conducted separately for each grade level. General information about nonroutine physics problems and problem posing was provided during these sessions. No content that could bias the sample was included. At the end of the presentations, the nonroutine physics problem-posing activity was assigned to the prospective teachers, who were asked to pose five nonroutine physics problems. Furthermore, emphasizing its importance for the research, they were also given the "Metacognition-Oriented Problem-Posing Opinion Form," which they were asked to complete immediately (without a break) after the problem-posing activity.

This activity, which took place in an unsupervised environment, did not constitute an exam, and there was no time limit so that the participants could spend enough time on metacognitive thinking and use their creativity freely. Most participants completed their tasks in approximately 1 to 2 h, and task completion times did not vary significantly. Furthermore, in line with the metacognitive focus of our research, prospective teachers were allowed to use resources such as notebooks, books, and other resources to help them "recognize what information they need" during the problem-posing process and practice how to utilize resources accordingly.

1. Nonroutine physics problem posing activity

Preservice physics teachers were asked to pose five nonroutine problems within the framework of Newtonian mechanics as part of the Mechanics I course. The course

and topic were selected because they are covered at all grade levels. The first four problems were based on the semistructured problem-posing strategy. This strategy was chosen because it allows students to develop more complex problems [35]. In this strategy, participants are asked to pose problems using given situations, figures, or graphs [36–39]. In the fifth question, the free problem-posing strategy was used, allowing the participants to generate original problems based on their own knowledge and experience [40]. Examples of the posed problems are presented in the Appendix (Figs. 1–5).

2. Problem-posing opinion form for metacognition

This section identifies the metacognitive strategies employed by prospective physics teachers during nonroutine physics problem posing. Metacognition involves the evaluation of the learning process and making judgments about one's own performance, as well as metacognitive monitoring [41]. However, due to its abstract nature and the uncertainty arising from involving multiple processes, it is difficult to measure [42]. Metacognitive judgments can be evaluated prior to, during, or following a performance, which is critical for ensuring research reliability [41,43]. Karakelle and Saraç classified the measurement techniques of metacognition as synchronous or asynchronous [28]. In synchronous measurements, methods such as thinking aloud are applied while participants are making decisions within the process; although effective, this approach may interfere with the process [44]. In asynchronous studies, metacognitive processes are assessed independently using Likert-type questionnaires or scales [28].

The studies by Efklides [45] and Karakelle and Saraç [28] served as the theoretical basis. Accordingly, nine questions were used in the opinion form, prepared according to the categories of ease of learning, learning decisions, sense of knowing, and confidence in the answer. An additional five questions were included to assess prospective teachers' perceptions of the problem-posing process and their beliefs about its instructional contributions.

Validity and reliability. Various measures were taken to ensure the validity and reliability of the data collection tools used in the study. To ensure the content validity of the problem-posing activity, the topic, problem content, and problem-posing strategies were carefully selected. The activity draft was reviewed by two physics teachers, a physics education specialist, and a field expert, and revised based on their feedback. In particular, the visual representations of the problem situations were made more understandable based on the physics education specialist's suggestions. Furthermore, to ensure language and semantic validity, a pilot study was conducted with ten preservice physics teachers and two physics teachers who were not included in the main study. The activity was finalized based on the feedback obtained.

The questions included in the metacognitive problem-posing feedback form were reviewed by experts to ensure content validity. Furthermore, the feedback form was administered immediately following the problem-posing activity to help participants accurately reflect on their metacognitive processes while they were still fresh. This approach aimed to increase accuracy and validity in their responses. A pilot study was conducted to test the clarity and comprehensibility of the form.

The reliability of the problem-posing activity and metacognition feedback form was ensured through several measures implemented during the development and implementation of the measurement tools. Accordingly, identical instructions were provided to all participants under the same conditions. Administering the metacognition feedback form immediately after the activity ensured that participants accurately reported their metacognitive experiences while they were still fresh and increased the reliability of the responses. Furthermore, during the development process, the opinions of two experienced teachers and two field experts were sought to ensure that the questions were equally understandable to everyone, to enhance response consistency. Similarly, necessary revisions were made based on the pilot study findings to ensure stable and consistent results.

VI. DATA ANALYSIS

A. Analysis of nonroutine problem-posing activity

In evaluating the problems posed by preservice physics teachers, a rubric was employed to standardize evaluation criteria and minimize researcher subjectivity. This enhanced the reliability of the study by ensuring that different evaluators consistently obtained consistent results over time.

In the analyses, the codes A, B, C, and D—assigned to prospective teachers based on their grade levels—were retained. Each problem posed by the participants was scored individually on a 70-point scale, and then each participant's overall problem-posing performance was computed. Subsequently, the arithmetic means were computed for each grade level to evaluate their ability to pose nonroutine physics problems.

The rubric used in this study was theoretically grounded in the framework developed by Ergün *et al.* [46], which was designed to assess students' problem-design performance in an introductory university-level physics course. According to this rubric, the problems posed by students are evaluated across six categories: comprehensibility (language and expression), alignment with physics principles, problem structure, number of questions posed, problem type, and problem solvability.

In this study, the "Number of Questions Asked" category from the original rubric was omitted because the number of problems the preservice physics teachers were asked to pose was predetermined by the researchers for research purposes. Additionally, a new category, "*Problem Poser Correctly Solves the Problem They Posed*," was introduced

TABLE I. Nonroutine problem-posing activity scoring criteria.

CRITERIA
Type of problem
What is the type of problem designed?
1. It is a nonroutine problem type that requires thinking. (20 points)
2. It is a routine, simple problem type. (0 points)
Structure of the problem
Is the problem setup in the desired instruction?
1. The given information in the instruction scenario is included in the problem setup completely (15 points)
2. There is missing data in the problem (0 points)
Compatibility of the problem with physics principles/scientificity
Are the information, concepts, rules, and shapes in the problem given in accordance with physics principles?
1. The problem is not compatible with physics principles (0 points)
2. The problem is compatible with physics principles but incompatible with real life. (5 points)
3. The problem is compatible with physics principles. (10 points)
Problem solvability
Is the problem designed as a solvable problem?
1. The structure of the problem is invalid, so it is not solvable. (0 points)
2. The information and data in the problem are not sufficient to solve the problem. (5 points)
3. The problem can be solved, but unnecessary/extra data is used in the problem situation. (8 points)
4. The problem can be solved, and the data are complete and appropriate. (10 points)
The problem maker tests the solvability of the problem he or she posed according to the instructions. Was the problem solved correctly?
1. The person did not solve the problem he or she posed. (0 points)
2. He or she solved the problem incorrectly (processing error, incorrect use of data, carelessness, etc.) (8 points)
3. The person solved the problem he or she posed without any errors. (10 points)
Comprehensibility of the problem (language and expression): Is the problem expressed clearly and understandably?
1. The problem text is not clear and understandable. (0 points)
2. Problem text is understandable, but the expressions are careless. (3 points)
3. Problem text is clear and understandable. (5 points)
Rubric total points: 70

to assess whether participants were able to solve the problems they created. These modifications were implemented to better align the rubric with the specific aims and context of the present study (see Table I).

In the original study [46], the reliability of the rubric was examined through interrater and intrarater consistency analyses, yielding a Pearson correlation coefficient of $r = 0.86$ between two raters and $r = 0.92$ for the same rater on rescoring. In the present study, revisions to the rubric were made based on expert opinions in the field. To further ensure reliability, the rubric was scored independently by two researchers, ensuring a high level of consistency before being finalized.

B. Analysis of the problem-posing opinion form for metacognition

Immediately after the nonroutine problem-posing activity, the participants' responses to the metacognitive problem-posing opinion form were analyzed. The form, developed according to the categories of ease of learning, learning decisions, sense of knowing, and confidence in the answer, was analyzed, and comments were made on how active the prospective teachers were in each skill. During the analysis, the questions were labeled Q1, Q2, Q3, …

VII. RESEARCH RESULTS

A. Skill levels of preservice physics teachers in nonroutine problem posing

Determining the problem-posing skill levels of preservice physics teachers is an important indicator in assessing their creativity and pedagogical competence. In this study, the activity in which preservice physics teachers posed nonroutine physics problems using their physics knowledge and pedagogical understanding was evaluated, and the scores obtained by the preservice physics teachers for this activity were computed. The maximum score for this five-question activity is 350. The calculated values for nonroutine physics problem-posing skills are presented in Table II.

As shown in Table II, the overall average performance of participants in posing nonroutine physics problems is 59.22%. This result indicates that their performance in posing nonroutine physics problems is at a slightly above-average level of proficiency.

B. Preservice physics teachers' problem-posing skills by grade level

The analysis revealed that preservice physics teachers' nonroutine physics problem-posing skills tended to improve with increasing grade level. As shown in

TABLE II. Nonroutine problem-posing performances of preservice physics teachers.

Class	Q1	Q2	Q3	Q4	Q5	Total	f (%)
A1	25	0	36	31	31	123	35, 14
A4	21	0	33	21	0	75	21, 42
A5	59	50	35	70	33	247	70, 57
A9	21	48	61	66	25	231	66, 0
A10	53	66	68	49	21	247	A10
Total point	179	164	233	237	110	% average	52, 74
B1	35	33	0	0	0	68	19, 42
B4	34	13	54	24	25	150	42, 85
B5	35	66	55	66	63	285	81, 42
B6	53	21	45	43	20	182	52, 0
B7	18	65	33	0	0	116	33, 14
Total point	175	198	187	133	108	% average	45, 77
C1	43	35	68	33	70	249	71,14
C2	42	21	35	31	35	164	46,85
C6	33	35	60	64	70	262	74,85
C7	31	36	33	58	35	193	55,14
C10	51	65	68	68	66	318	90,85
Total point	200	192	264	254	276	% average	45, 77
D1	33	35	35	15	68	186	53, 14
D4	70	68	68	53	68	327	93, 42
D7	70	66	61	23	66	286	81, 71
D8	28	23	51	35	38	175	50, 0
D9	51	70	33	58	50	262	74, 85
Total point	252	262	248	184	290	% average	70, 62

Table II, fourth-year students (group D) achieved the highest total average score, followed by third-year students (group C). While first-year students (group A) demonstrated a moderate level of performance, the lowest average score was observed among second-year students (group B).

The final question in the free problem-posing type differs from the first four in nature. This problem type requires prospective teachers to regulate their own thinking processes through metacognitive engagement. As shown in Table II, this item yielded the lowest scores among first- and second-year students, whereas third- and fourth-year students achieved the highest scores. The superior performance of upper-grade students on the free problem-posing task suggests the influence of metacognitive maturation on their problem-posing abilities.

C. Metacognitive strategies in the process of posing nonroutine physics problems

The "Ease of Learning" category of the problem-posing opinion form for metacognition, which was designed to identify the metacognitive strategies employed by participants in the process of posing a nonroutine physics problem, included the following items:

Q1: Before starting to pose a problem, did you consider which topic-related knowledge you needed to include in your question?

TABLE III. Frequency and percentage values of the answers given to the questions in the ease of learning category.

Answers	Q1: f (%)	Q2: f (%)
Never/not at all	0 (0)	0 (0)
Very little	2 (10)	2 (10)
Partially	2 (10)	3 (15)
Mostly	4 (20)	5 (25)
Completely	12 (60)	10 (50)
Total	20 (100)	20 (100)

Q2: Before starting to pose a problem, did you think in detail about the given and requested information about the topic?

The frequency and percentage of the responses to these items are presented in Table III.

According to the responses given to Q1, the majority of the participants stated that they thought about the needs related to the subject completely or mostly before starting the problem-posing task. The rate of those who thought partially or very little is lower; there were no participants who stated that they did not think at all. Similarly, in Q2, half of the participants stated that they thought completely about the given and requested, and one-fourth stated that they thought mostly. There were fewer participants who thought partially or very little, and there were no participants who stated that they did not think at all for this question.

An analysis of Table III reveals that the majority of participants engaged in thinking and planning to facilitate learning before the task, suggesting that they actively employed metacognitive strategies such as planning and task analysis.

Questions 3, 4, and 5 of the problem-posing opinion form for metacognition were designed to assess the "Learning Decisions" category within metacognitive thinking skills. The questions were as follows:

Q3: When posing the problem, did you consider all possible solutions?

Q4: Did you attempt alternative methods when posing the problem?

Q5: When posing the problem, did you utilize question types you had previously encountered (such as those encountered in textbooks or those with which you were proficient)

The evaluations of the responses received from the preservice physics teachers are presented in Table IV.

Table IV shows that only three students responded "very little" to question Q3, while the remaining 17 students responded "mostly" and "completely," indicating that they considered different methods and solutions when posing the problem. Findings for question Q4 revealed a decrease in the number of "mostly" and "completely" responses, with some participants either not posing alternative problems at all or posing them "very little." Findings for question Q5 revealed that seven participants either did not use previous problem patterns for which they knew the

TABLE IV. Frequency and percentage values of responses given to the learning decisions category questions.

Answers	Q3: f (%)	Q4: f (%)	Q5: f (%)
Never/not at all	0 (0)	1 (5)	4 (20)
Very little	3 (15)	2 (10)	3 (15)
Partially	0 (0)	6 (30)	4 (20)
Mostly	9 (45)	6 (30)	6 (30)
Completely	8 (40)	5 (25)	3 (15)
Total	20 (100)		20 (100)

solutions or used them very rarely, while others used them to a greater extent.

An analysis of Table IV reveals that the majority of participants consider all possibilities and make strategic decisions. However, they are less proficient in making decisions about applying alternative problem-posing methods. The majority of participants believe they make strategic decisions by drawing on their past experiences. We can conclude that the result for question Q5 also supports the category of "Ease of Learning."

The sixth question of the metacognitive problem-posing opinion form was asked to evaluate the "Feeling of Knowing" category in metacognitive thinking skills.

Q6: Did you check the suitability of the problem you posed for your purpose?

Accordingly, the evaluations regarding the answers received from the preservice physics teachers are given in Table V.

As shown in Table V, none of the preservice physics teachers selected the responses "never" or "very little." On the other hand, it was found that 70% checked the suitability of the problems they posed for the purpose with the answers "completely" or "mostly." It was determined that 30% reported checking suitability partially.

The findings from Table V reveal that 70% of the prospective teachers had the ability to assess their own knowledge and understanding during the problem-posing process. The participants are able to actively use their sense of knowing by evaluating whether the problems they posed align with their intended goals.

Questions 7, 8, and 9 were designed to assess the "Confidence in the Answer" category of the problem-posing opinion form for metacognition.

TABLE V. Frequency and percentage values of the answers given to the question of the feeling of knowing category.

Answers	Q6: f (%)
Never/not at all	0 (0)
Very little	0 (0)
Partially	6 (30)
Mostly	5 (25)
Completely	9 (45)
Total	20 (100)

Q7: After posing the problem, did you make the necessary checks for criteria such as language, appropriateness of units used, redundancy of information, and missing data?

Q8: After posing the problem, did you check its solvability?

Q9: Were you aware of the strategies you employed while posing the problem?

The findings related to this category are in Table VI.

For question Q7, the data in Table VI indicate that the majority of participants (65%) either "mostly" or "completely" checked the content of the problems they posed. This suggests that participants consciously used a control mechanism to ensure the accuracy and quality of their problems and their solutions.

The findings for question Q8 indicate that all participants solved the problems they posed. This situation shows that the participants preferred to ensure that the problems they posed were correct. When viewed from the perspective of confidence in the answer, it can be said that the participants used verification and self-assessment strategies.

The data in Table VI for Q9 show that 60% of the participants were aware of the strategies they employed during the problem-posing process. This finding supports the existence of strategic awareness, as participants demonstrated the use of both the content-checking (Q7) and accuracy-testing (Q8) strategies.

D. Preservice physics teachers' beliefs about posing nonroutine problems and using them in teaching

This section examines the preservice physics teachers' reflections on their experiences of posing a nonroutine physics problem and the perceived implications of this process for physics teaching. Following the experience, participants' perceptions of problem posing as easy/difficult, whether they consider themselves competent in this skill (feeling of knowing), their beliefs that future problems will be understandable and solvable (confidence in the answer, feeling of knowing), and their beliefs that the problems they pose will lead to effective learning in physics teaching (confidence in the answer). The corresponding questions presented to the participants were as follows:

Q10: Do you think problem posing is generally easy?

Q11: Do you think posing a nonroutine problem is easy?

Q12: Do you feel competent in problem posing?

TABLE VI. Frequency and percentage values of answers given to questions in the confidence in answer category.

Answers	Q7: f (%)	Q8: f (%)	Q9: f (%)
Never/not at all	0 (0)	0 (0)	0 (0)
Very little	3 (15)	0 (0)	2 (10)
Partially	4 (20)	0 (0)	6 (30)
Mostly	7 (35)	6 (30)	4 (20)
Completely	6 (30)	14 (70)	8 (40)
Total	20 (100)	20 (100)	20 (100)

TABLE VII. Perceptions and beliefs of preservice physics teachers regarding nonroutine physics problem posing and its impact on physics teaching.

Answers	Q10: f (%)	Q11: f (%)	Q12: f (%)	Q13: f (%)	Q14: f (%)
Never/not at all	7 (35)	8 (40)	4 (20)	0 (0)	0 (0)
Very little	1 (5)	6 (30)	1 (5)	1 (5)	3 (15)
Partially	9 (45)	5 (25)	7 (35)	4 (20)	3 (15)
Mostly	2 (10)	0 (0)	5 (25)	9 (45)	4 (20)
Completely	1 (5)	1 (5)	3 (15)	5 (25)	10 (50)
Total	20 (100)	20 (100)	20 (100)	20 (100)	20 (100)

Q13: Do you believe your problems will be understandable and solvable?

Q14: Do you believe the problems you pose will foster effective learning in physics teaching?

Table VII reveals that participants' responses to Q10 and Q11 reflect substantial difficulty in problem posing and nonroutine problem posing. The number of participants who responded "never/not at all" and "very little" increased notably, particularly for nonroutine problem posing. These findings suggest that problem posing, especially nonroutine problem posing, requires higher-order thinking skills and is perceived as a complex cognitive task. Furthermore, participants who reported greater perceived difficulty in problem posing may also be considered to be aware of the metacognitive demands of the task expected of them.

According to the findings of Q12 in Table VII, it was concluded that the majority of participants perceived themselves as competent in problem posing. Despite recognizing the process as challenging, the results from Q10 and Q11 revealed that they were able to assess themselves as competent in problem posing, that they were aware of their own strengths and weaknesses, and that they possessed self-assessment skills. These results are consistent with the feeling of knowing results in Table V.

According to the findings of Q13 in Table VII, the vast majority of participants believed that the problems they pose in the future will be understandable and solvable. This belief suggests that prospective teachers are active in metacognitive prediction (a feeling of knowing about the future) and evaluative judgment (confidence in the answer) strategies. These results are consistent with the results for confidence in the answer presented in Table VI.

For Q14 in Table VII, the majority of participants demonstrated confidence in the problem-posing process and in the quality of the problems they posed. This confidence suggests that participants perceived the problems they posed not merely as assessment tasks, but as cognitive and pedagogical tools that can facilitate meaningful learning and instructional engagement in physics education.

VIII. DISCUSSION

The findings indicate that the nonroutine problem-posing skills of preservice physics teachers generally improved with increasing grade level, except for second-year students. Although the physics teacher education curriculum does not include courses specifically designed to develop problem-solving or problem-posing abilities, the observed improvement can be attributed to the cumulative theoretical knowledge and pedagogical experience gained as students progress through the program. Another plausible explanation is that students' interest in nonroutine problems increases over time as they gain experience in problem solving, as demonstrated by the work of Krulik and Rudnick [47]. A similar pattern was observed for the free problem-posing task, which required preservice physics teachers to actively engage their metacognitive skills. The finding of higher performance with increasing grade level suggests that prospective teachers demonstrate not only cognitive but also metacognitive development as their grade level increases. Consistent with prior research on the free problem-posing abilities of primary school students [48,49], this result highlights that higher-grade prospective teachers are more capable of monitoring and regulating their own thinking processes when engaging in complex, open-ended tasks such as free problem posing.

It is noteworthy that the lowest performance in second grades does not conform to the increasing performance pattern observed at other grade levels. A similar result was found in the work of Guo *et al.* on Chinese middle school students' mathematical problem-posing performance [50]. The researchers found that problem-posing performance fluctuated across grade levels. The most likely reason for this is that second graders, unlike first graders, are not taking solely introductory courses, but are instead focusing on physics and education courses and beginning to transition into the teaching profession. This transitional phase may temporarily challenge their ability to integrate content knowledge with pedagogical and metacognitive strategies during problem-posing tasks.

During this process, first-year students primarily engage with foundational course content, whereas second-year students begin to encounter more discipline-specific, theoretical, and pedagogical coursework. Consequently, this transition may have challenged their ability to apply their newly acquired theoretical knowledge to practical problems. In addition, second-year students' motivation may have been relatively lower due to the increased cognitive and academic demands of these courses. Another possible

explanation may be the low academic achievement of the second-year sample selected for the study. This interpretation is supported by the findings of Çıldır and Sezen [51], who reported that preservice physics teachers with higher academic achievement also demonstrated stronger problem-posing skills. Given this possibility, the findings regarding second-year students should be evaluated cautiously in terms of generalizability.

Another noteworthy finding of the study was that the overall performance average in problem posing was 59.22%. This indicates that while the current curriculum provides prospective teachers with problem-posing experience, it still requires improvement. Consistent with this, Yıldıs study with prospective middle school mathematics teachers reported similar results, emphasizing that problem-posing skills are a key consideration in the design of teacher preparation programs [52]. The findings of the present study similarly suggest that problem-posing skills should be systematically developed across all grade levels, with greater emphasis on integrating problem-posing and problem-solving activities into physics teacher education programs. Supporting this view, Polat and Özkaya [6] also concluded that activities using a problem-posing approach improve students' problem-posing skills. Nonroutine physics problem activities, in particular, will contribute to prospective teachers' gaining both experience and developing more creative and analytical thinking skills.

Findings related to research question 3 indicate that preservice physics teachers employ metacognitive strategies when posing nonroutine physics problems. Specifically, within the "Ease of Learning" category, many participants reported that they tend to consider their needs related to the subject (Q1) and the context of givens and desired outcomes (Q2) prior to posing it. This finding suggests that participants are able to use cognitive preparation strategies before starting the problem-posing task. This suggests that preservice physics teachers generally have high levels of cognitive preparation and a tendency to mentally plan for the subject. Such preparatory behaviors reflect that participants make predictions about elements that will facilitate the problem-posing task and are active in the "ease of learning" category in their metacognitive regulation. Zimmerman reached a similar conclusion, highlighting the self-regulatory dimensions of the learning process, emphasizing that successful learners employ cognitive and affective preparation strategies before beginning a task [53]. In this context, preservice teachers' reflection on what is given and what is desired (Q2) can be interpreted as an indicator of their planning behaviors related to task analysis. Such planning behaviors are considered to enhance the quality of both the process and the outcomes in complex tasks such as problem posing.

"Learning decisions" from metacognitive strategies require an individual to consciously decide what to do and which strategies to use during a learning task. The findings from this study revealed that preservice physics teachers considered various methods and solutions for the problem and its solution when posing problems, but they were not sufficiently proficient in considering alternative problems. In tasks such as creative problem solving, experimenting with alternative methods is important for the development of higher-order cognitive processes [54]. Likewise, experimenting with alternative methods and generating multiple problem formulations during problem posing are essential indicators of cognitive flexibility. In this context, the findings suggest that participants are weak in their flexible thinking skills and need to be supported. The findings for Q5 indicated that the majority of prospective teachers were influenced by the types of questions they had previously encountered when posing their own problems. This suggests that prospective teachers tend to approach the task more rote-based, relying solely on recall. This outcome could also be attributed to the difficulties experienced with the final question, which required free problem-posing skills. It would be highly beneficial for prospective teachers to conduct research to develop their skills in using previously encountered question types in posing new and more complex problems. Accordingly, it would be advantageous to further enrich the curriculum for prospective physics teachers by incorporating components aimed at fostering flexible thinking and creativity.

During the problem-posing process, a feeling of knowing enables individuals to identify what they know about a topic, what they do not know, and how their lack of knowledge may influence the problem posed. Findings in the "Feeling of Knowing" category of metacognitive thinking skills indicated that the majority of participants (approximately 70%) evaluated the appropriateness of the problems they posed, that is, whether they were nonroutine problems that aligned with the given instructions. As preservice physics teachers gain more experience, their developing sense of knowing is likely to influence both the quality and the complexity of the problems they generate, while also enhancing their self-confidence in problem-posing tasks.

Within the "Confidence in Answer" category, the findings indicated that the majority of preservice physics teachers (65%) evaluated the problems they posed in terms of language accuracy, unit consistency, and the presence of missing or redundant data. This result implies that participants tend to assess both the form and content of their problems and place particular importance on the overall quality of their products. Furthermore, the data revealed that participants strengthened their confidence by testing the solvability of the problems they constructed. Analysis of Q9 responses indicated that some participants were either unaware of the strategies they use when posing problems or did not consciously select them. This result suggests that, although metacognitive awareness is developing, some participants lack confidence, particularly in strategy selection, and require further support.

Furthermore, the metacognitive strategies employed by preservice physics teachers in the problem-posing process overlap with problem-solving models frequently discussed in physics education research. For instance, the "Ease of Learning" category corresponds to both Polya's "understanding the problem" stage, which is the initial step of problem solving, and Docktor and Mestre's "qualitative analysis" dimension [55,18]. It also parallels the work of Heller *et al.* on "creating a physical representation" stage [56]. Similarly, the "Learning Decisions" category aligns with Polya's "devising a plan/strategy for a solution" phase and Schoenfeld's "thinking about and implementing solution strategies" dimension [55,57].

The feeling of knowing strategy observed in preservice physics teachers overlaps with the monitoring and evaluation processes emphasized by Reif and Heller [48]. Finally, the Confidence in the Answer category involves checking the posed problem for aspects such as linguistic clarity, unit consistency, and solvability. In this context, this strategy mirrors Polya's "looking back" step and Schoenfeld's "reflection" or "reflective decision-making" dimension [55,57]. In summary, these four metacognitive categories represent not only individual awareness processes for participants but also reflections of the metacognitive stages articulated in problem-solving models within the physics education research literature.

Considering the perceptions, beliefs, and competencies of preservice physics teachers regarding the process of posing nonroutine physics problems, a substantial proportion of participants perceived problem posing—particularly nonroutine tasks—as a challenging endeavor. This finding aligns with the performance results, which showed that their problem-posing scores were slightly above the midrange across all grade levels. The perception of problem posing as a difficult process suggests that prospective physics teachers require more structured and scaffolded experiences to develop competence and confidence in this area.

The majority of participants consider themselves moderately competent in problem posing and believe that the problems they pose are understandable and solvable. Nevertheless, although they perceived the process as challenging, their confidence in producing comprehensible and solvable problems reflects the activation of metacognitive processes related to the sense of knowing and confidence in the answer.

Another notable finding is that more than half of the preservice physics teachers believed that problem posing can enhance effective learning in physics education. This belief reflects their tendency to employ a "feeling of knowing strategy" for future problems. In other words, after experiencing problem posing, they can demonstrate metacognitive behaviors such as making predictions about future situations, planning what to do and how to do things, and making decisions.

The significance of this study lies in its identification of the extent to which preservice physics teachers utilize metacognitive strategies when posing nonroutine physics problems. However, exploring the underlying mechanisms and reasoning processes that explain how and why these strategies are used was beyond the scope of the present study. Future studies exploring how and why prospective teachers think during this process, through written explanations or in-depth interviews, would significantly contribute to the field.

The findings are significant in that they illuminate how prospective physics teachers perceive and employ metacognitive strategies when posing nonroutine physics problems. Nevertheless, several methodological limitations should be taken into account when interpreting these results. Accordingly, the key limitations that may influence the scope and interpretability of the study are outlined below.

IX. LIMITATIONS

In this study, the use of metacognitive strategies was assessed through a Likert-type questionnaire based on preservice teachers' self-reports. Although Likert-type items are useful for capturing participants' perceptions regarding their use of specific strategies, they do not fully reflect the depth of metacognitive processes or how these strategies are enacted in practice. Consequently, the findings should be interpreted as indicators of self-reported awareness and are limited to describing the extent to which preservice teachers believe they use metacognitive strategies. Future research could strengthen the field by examining *why* and *how* preservice teachers engage in metacognitive thinking during problem posing, for example, through written reflections or in-depth interviews.

The problem-posing task was also administered in an unsupervised manner to create conditions that more closely reflected the preservice teachers' natural problem-posing processes. However, this unsupervised setting introduces uncertainty regarding whether, and to what extent, participants made use of external resources (e.g., textbooks, online materials, or AI-based tools) during the task. Incorporating additional data collection methods to identify external resource use in future studies could enhance the breadth and richness of process-related data.

X. CONCLUSIONS

In conclusion, this study offers valuable insights into the mindsets, cognitive flexibility, analytical thinking skills, and creativity of preservice physics teachers in the context of posing nonroutine problems. The participants' performance in this process reflected not only their individual competence but also their level of metacognitive strategy use. The findings concerning the types and frequency of these strategies are particularly significant, as they are likely to shape the instructional approaches and learning environments that these future teachers will design for their students.

The findings of this study suggest several important implications for the design of physics teacher education programs. First, preservice physics teachers should be

provided with structured yet open-ended tasks that stimulate creativity rather than focus solely on standard problem solving. Moreover, they should be encouraged to pose novel problems based on diverse scenarios and perspectives. Teacher education programs should also incorporate activities that promote the development of alternative solution strategies, where multiple approaches can be tested and discussed collaboratively. Such practices are likely to enhance the flexible thinking skills of future physics teachers, which may in turn be reflected in their classroom practices. Finally, curricula should include more open-ended and reflective questions to foster preservice physics teachers' ability to monitor and regulate their own thinking processes.

XI. ETHICS APPROVAL

All procedures performed in social studies involving human participants comply with ethical standards. It was reviewed by the Hacettepe University Ethics Committee with protocol number E-51944218-300-00001421081.

This article is derived in part from the master's thesis of the first author (A. K.), completed under the supervision of the second author (S. Ç.).

DATA AVAILABILITY

The data are not publicly available. The data are available from the authors upon reasonable request.

APPENDIX

The appendix includes examples of questions posed by preservice physics teachers.

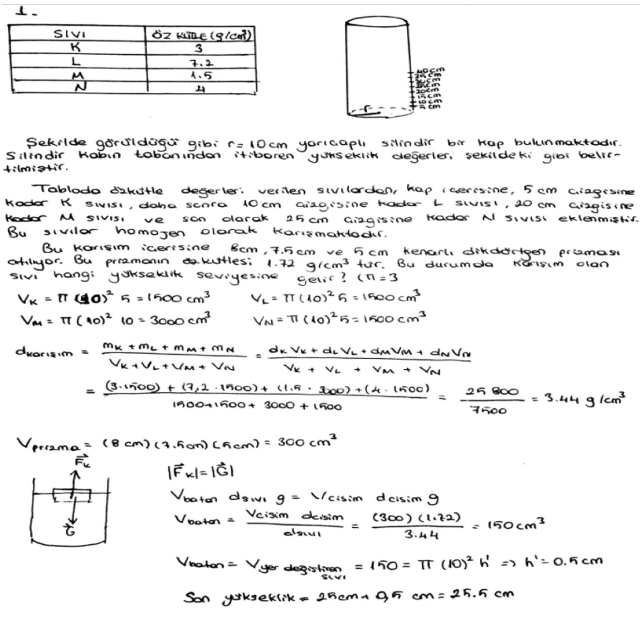


FIG. 1. Question designed by the preservice physics teacher with code D4 for problem 1. [English translation of the question: "As seen in the figure, there is a cylindrical container with a radius of $r = 10$ cm. The height values from the base of the cylindrical container are specified as in the figure. From the liquids given in the table with density values, liquid K is added into the container up to the 5 cm mark, then liquid L up to the 10 cm mark, liquid M up to the 20 cm mark, and finally liquid N up to the 25 cm mark. These liquids mix homogeneously. A rectangular prism with edges 8, 7.5, and 5 cm is placed into this mixture. The mass of this prism is 1.72 g/cm^3. In this case, to what height level does the liquid mixture reach? ($\pi = 3$)"].

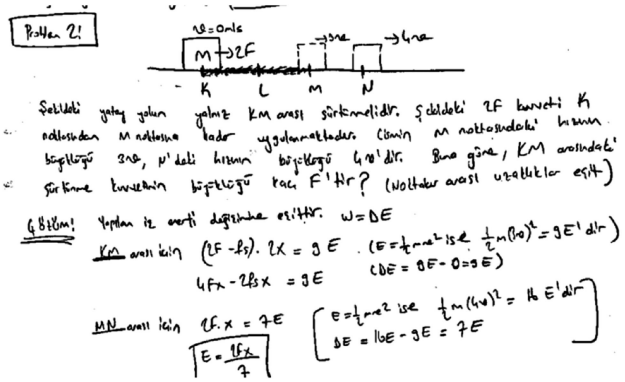


FIG. 2. Question designed by the preservice physics teacher with code D9 for problem 2. [English translation of the question: The horizontal path in the figure is frictionless except for the KM section. The 2F force in the figure is applied from point K to point M. The magnitude of the velocity of the object at point M is 3V, and the magnitude of its velocity at point N is V. Accordingly, how many F is the magnitude of the frictional force between KM? (Distances between points are equal)].

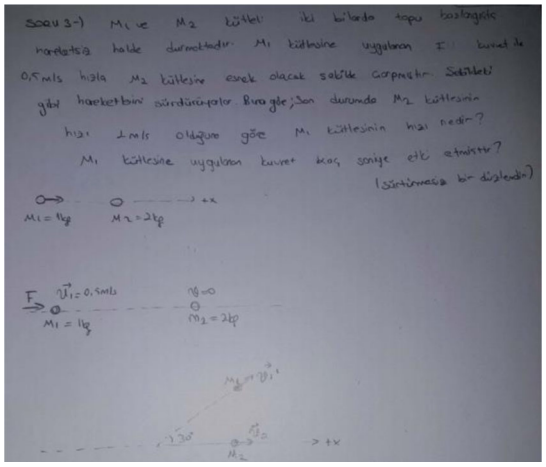


FIG. 3. Question designed by the preservice physics teacher with code B6 for problem 3. [English translation of the question: Two billiard balls with masses M1 and M2 are initially at rest. The F force applied to mass M1 causes it to collide elastically with mass M2 at a speed of 0.5 m/s. They continue their motion as shown in the figure. Accordingly, if the final speed of mass M2 is 1 m/s, what is the final speed of mass M1? How many seconds did the force applied to mass M1 act? (On a frictionless plane)"].

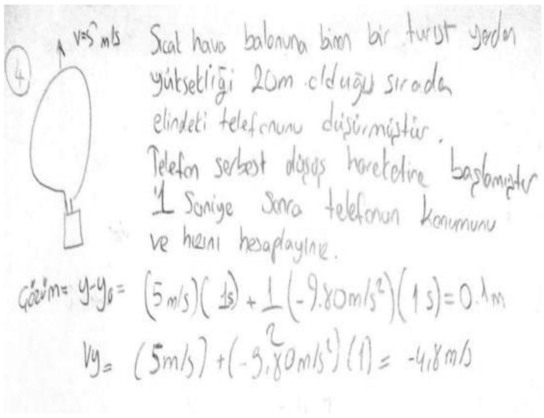


FIG. 4. Question designed by the preservice physics teacher with code C2 for problem 4. (English translation of the question: A tourist riding a hot air balloon dropped their phone when the balloon was 20 m above the ground. The phone started free falling. Calculate the position and velocity of the phone after 1 s).

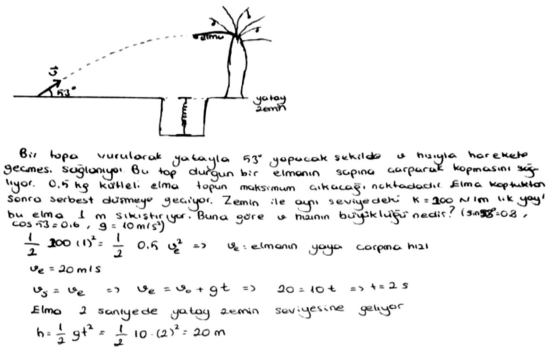


FIG. 5. Question designed by the preservice physics teacher with code D6 for problem 5. [English translation of the question: A ball is hit and set in motion with a velocity v, making an angle of 53° with the horizontal. This ball causes a stationary apple to break by hitting its stem. The 0.5 kg apple is at the point where the ball will rise to its maximum. After breaking, the apple goes into free fall. There is a spring with a spring constant of $k = 200$ N/m at the same level as the ground. The apple compresses the spring by 1 m. Accordingly, what is the magnitude of the velocity v? (sin 53: 0.8, cos 53: 0.6, $g = 10$ m/s^2)].

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