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Analysis of Physics Problem Solving Skills of Junior High School Students through PBL-HOTS on Magnetism Material

Nurhasan Ropi`i*, Sunyoto Eko Nugroho, Ellianawati

Master of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia

*Correspondence to: *nurhasanropii@students.unnes.ac.id*

Abstract: Critical thinking and problem-solving skills are essential components of 21st-century education goals. Weak problem-solving and higher-order thinking skills (HOTS) can become problematic for students studying physics, particularly in the context of magnetism. To address this issue, efforts are being made to improve physics problem-solving skills through the application of problem-based learning (PBL) and HOTS. The study aims to determine whether students' physics problem-solving skills are better when using PBL-HOTS compared to PBL alone. Additionally, the study aims to determine the improvement and profile of physics problem-solving skills according to Heller after the application of PBL-HOTS on magnetism material. The study employed a mixed-methods sequential explanatory pre-test post-test control group design. The participants were ninth-grade students from SMP Negeri 1 Kersana during the 2021/2022 academic year. The sample was selected using purposive sampling, with Class IX A as the experimental group and Class IX C as the control group. Data was collected using a physics problem-solving test, including descriptions, interviews, and post-test documentation checks. The t-test results indicate that students who applied PBL-HOTS had better physics problem-solving skills than those who applied PBL. Additionally, the N-Gain test showed a moderate increase in students' physics problem-solving skills after the application of PBL-HOTS, with an average N-Gain score of 0.4785. The results of interviews and examination of posttest documentation support Heller's profile of students' physics problem-solving skills. This includes indicators of focusing on the problem (84.69%), describing physics concepts (70.94%), planning solutions (87.81%), implementing problem-solving plans (95.63%), and evaluating solutions (46.88%).

Keywords: Physics problem solving skills, PBL-HOTS, Magnetism material

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Introduction

The 21st century education is centered around the development of 4C competencies: critical thinking and problem-solving, creativity, communication, and collaboration skills (Saputra *et al.*, 2019). The mastery of concepts is not the only learning objective, but also the application of these concepts to solve real-life problems hari (Kaniawati *et al.*, 2015). According to Sulianto *et al.* (2018), there is a positive correlation between high critical thinking skills and the ability to solve problems in learning.

The issue of physics education at the junior high school level is the students' weak problem-solving ability. In the classroom, teachers tend to prioritize students' mastery of physics concepts over their ability to solve physics problems (Azizah *et al.*, 2015). According to Sujarwanto *et al.* (2014), students are typically capable of solving physics problems that involve simple mathematical calculations, but struggle with more complex problems. Weaknesses in problem-solving ability among students are indicated by difficulties in understanding the problem, developing a solution plan, implementing the plan, and rechecking the results (Putri & Sari, 2020). Furthermore, according to the 2018 PISA research conducted by the Organization for Economic Cooperation and Development (OECD), Indonesian students scored 396 in problem-solving skills for science performance, which is below the average score of 489. This places Indonesia in the low category among 71 out of 79 countries (Rosana *et al.*, 2020). According to the 2022 PISA results, Indonesian students' science performance in problem-solving skills scored 383, a 13-point decrease from the 2018 results. This places Indonesia in the low category, ranking 67th out of 81 countries (OECD, 2023).

Problem-solving is a cognitive conflict that students experience and can be resolved through experience and natural interactions (Arends, 2012). Developing procedures to improve problem-solving skills is necessary because these skills involve high-level mental processes that are not easily mastered by students

(Bancong & Subaer, 2013). The relevance of problem-solving skills lies in the ability to think about complex problems through higher-order thinking skills (HOTS). Problem-solving skills represent an integral component of HOTS skills, classified at the analysis, evaluation, and creation levels. The ability to engage in problem-solving activities has been demonstrated to exert a positive influence on students' comprehension of the concepts they learn, particularly those related to physics. Conversely, students who possess superior problem-solving skills will develop adaptability in the real world.

The facilitation of HOTS by teachers can enhance students' awareness of their own thinking and promote their learning performance and cognitive growth (Saido *et al.*, 2015). It is important to activate HOTS skills when students face unfamiliar problems, uncertainties, questions, or dilemmas during the learning process. The implementation of HOTS in the classroom can enhance students' capacity to explain, make decisions, communicate, and produce valid products based on available knowledge and experience, while also fostering the development of other intellectual skills. HOTS skills demand that students transfer scientific knowledge and apply it to novel situations (Gillies *et al.*, 2014).

HOTS encompass the transfer of knowledge, critical and creative thinking skills, and problem-solving abilities (Ariyana *et al.*, 2018). Marzano proposed several levels of HOTS, including comparing, classifying, inducing, making inferences, analyzing errors, developing support, conducting perspective analysis, abstracting, making decisions, investigating, solving problems, conducting experimental investigations, and making discoveries (Heong *et al.*, 2011). Krathwohl (2002) stated that indicators for measuring HOTS include analyzing, evaluating, and creating. These indicators align with the problem-solving abilities outlined by Heller & Heller (2010), which include: (1) focusing on the problem, (2) describing the relevant physics concept, (3) planning the solution, (4) executing the plan, and (5) evaluating the solution. The process of addressing a physics problem involves analyzing indicators in HOTS to focus on the problem and describe the physics concept. To plan a solution, execute the problem-solving plan, and provide evaluation, the indicators of evaluating and creating in HOTS are included. Students require HOTS skills to comprehend, analyze, evaluate, and create solutions to physics problems that can be applied in daily life.

Previous research has demonstrated that students' problem-solving skills can be enhanced through various methods. In a study conducted by Okafor (2019), students who were taught using Polya's problem-solving technique outperformed those who were taught using conventional problem-solving techniques in the context of physics learning. The Context and Problem Based Learning (C-PBL) model can enhance students' physics problem-solving skills, communication skills, confidence in learning, and conceptual understanding of physics lessons (Yuberti *et al.*, 2019). According to Reddy & Panacharoensawad (2017), inadequate math skills and lack of problem understanding are the primary hindrances to the development of problem-solving skills in physics. Hidayat *et al.* (2019) found a significant increase in students' mathematical problem-solving ability, as measured by their confidence level. This improvement was observed in students who received problem-based learning (PBL) with mind mapping for the effort and energy material, virtual media for the impulse and momentum material, and conceptual scaffolding for the object motion material, compared to those who received conventional learning (Asuri *et al.*, 2021; Hastuti *et al.*, 2017; Pucangan *et al.*, 2018). However, research that combines the application of Problem-Based Learning (PBL) with HOTS is still rare. Therefore, an effort that can be made is to integrate HOTS into PBL. The integration is done by modifying and improving the stages of PBL with HOTS skills when applied in learning. Providing HOTS problem exercises into PBL can also have a positive effect on improving students' problem-solving skills.

Physics learning materials at the junior high school level are integrated within the framework of science subjects. The material covers both concrete and abstract concepts. For instance, magnetism is a concrete physics subject taught in grade IX, which may be challenging for students to comprehend. To teach magnetism, a learning model that enhances students' physics problem-solving and higher-order thinking skills through the application of PBL-HOTS should be employed. The objective of this study is to compare the physics problem-solving skills of students who applied PBL-HOTS with those who applied PBL, to assess the improvement of students' physics problem-solving skills after applying PBL-HOTS, and to determine the profile of students' physics problem-solving skills according to Heller after applying PBL-HOTS.

Methods

The study employed a mixed-method sequential explanatory design with a pre-test and post-test control group. This type of research involves collecting and analyzing quantitative data in the first stage, followed by qualitative data collection and analysis in the second stage, which builds on the initial quantitative results (Cresswell, 2011; Sugiyono, 2013). The participants were ninth-grade students at SMP Negeri 1 Kersana during the 2021/2022 academic year. The sample selection utilized purposive sampling techniques based on several considerations. Firstly, the distribution of students in the population of ten ninth-grade classes was carried out evenly based on the report card grades of class VIII of the previous school year. This included the distribution of high-achieving, moderate, and underachieving students. Secondly, the distribution of the number of male and female students in each class in the population was also evenly distributed. The study was conducted with two classes, IX A as the experimental group and IX C as the control group. The research utilized descriptive tests, interviews, and post-test documentation as instruments.

The research procedure consists of three stages: preparation, data collection, and data analysis. The preparation stage entailed the creation of research instruments in the form of PBL-HOTS-based learning devices, HOTS description questions for pretest and posttest (totaling 10 questions), and structured interview guidelines for students regarding the concept of magnetism. These instruments were then validated by two expert validators: one Unnes physics lecturer and one science teacher who serves as the head of the Brebes Regency Science MGMP. The reliability of the pretest and posttest questions was determined by calculating Cronbach's Alpha using SPSS 25, which indicated their reliability. The collection of research data was conducted quantitatively through a pretest, treatment in the form of PBL-HOTS learning in the experimental group and PBL learning in the control group, and a posttest. The PBL-HOTS learning session consisted of six meetings, each spanning 15 lesson hours, and incorporated HOTS description question exercises. In contrast, the PBL learning session incorporated general description question exercises. Qualitative research data were collected through structured interviews following the posttest and posttest documentation to describe the profile of students' physics problem-solving skills according to Heller's framework on magnetism. The quantitative data analysis stage involved pretest and posttest results, which were analyzed using statistical tests such as t-tests and N-Gain tests. Qualitative data analysis was conducted by examining posttest documentation and conducting descriptive analysis of student interview results through the stages of data reduction, data presentation, and conclusion drawing.

Results and Discussion

This study applied problem-based learning (PBL) with higher order thinking skills (HOTS) in the experimental group and PBL alone in the control group to teach magnetism. The experimental and control groups were subjected to the same treatment, which was a Problem-Based Learning (PBL) intervention. The experimental group was provided with HOTS skills development through practice on HOTS description questions, while the control group engaged in practice on general description questions. The PBL syntax used followed Rusman's (2012) guidelines. (1) Introduce the problem to the students; (2) Arrange the students' learning process; (3) Provide guidance for individual and group experiences; (4) Develop and present their work; (5) Analyze and evaluate the problem-solving process. Krathwohl (2002) elaborated on the indicators of HOTS at the reasoning level, which include analyzing, evaluating, and creating. The PBL-HOTS syntax was derived from the PBL syntax and the reasoning level HOTS indicators. The PBL-HOTS syntax consists of six steps: (1) problem recognition; (2) problem description; (3) problem solving; (4) analysis of problem solving; (5) evaluation of problem solving results; and (6) creation of problem solving solutions.

Table 1. Data of Pretest and Posttest Values of Physics Problem Solving Skills

Statistic	Pretest		Posttest	
	Experimental Group	Control Group	Experimental Group	Control Group
N. Valid	32	32	32	32
Mean	57.63	57.25	77.19	68.31
Minimum	44	40	62	56
Maximum	76	78	96	82
Std. Deviation	7.491	9.126	9.531	7.904
Sig normality test	0.071	0.200	-	-
Sig homogeneity test	0.248		-	-
Sig t-test	0.858		0.000	

The study analyzed the problem-solving skills of the students in physics based on the results of the pretest and posttest administered to the experimental and control groups in order to generate ratio data. Two rounds of data analysis were performed. The first analysis involved testing the initial ability of the experimental and control groups using normality tests, homogeneity tests, and t-tests of pretest results. The second analysis involved using t-tests and N-Gain tests of posttest results to draw conclusions about the students' physics problem-solving skills. Table 1 presents the data from the pretest and posttest results of problem-solving skills.

Based on Table 1, the quantitative analysis of pretest results indicates that the experimental group and the control group had the same initial problem-solving skills, as indicated by the mean value of the pretest. The significance values of the normality test, homogeneity test, and t-test on the pretest are all greater than the significance level of 0.05. Therefore, it can be concluded that the experimental group and control group are normally distributed, homogeneous, and there is no significant difference between the two.

Based on Table 1, the quantitative analysis of posttest results indicates that the average posttest value of physics problem-solving skills in the experimental group is superior to that of the control group. The t-test results show a significance value smaller than the significance level of 0.05. Therefore, it can be concluded that the physics problem-solving skills of students in the experimental group who applied PBL-HOTS are better than those of students who applied PBL.

The statistical test results indicate that students who received PBL-HOTS magnetic material demonstrated better physics problem-solving skills than those who received PBL alone. This finding is supported by Simanungkalit *et al.* '*s* (2019) research, which found that students exposed to problem-based learning based on higher-order thinking skills achieved greater learning outcomes than those exposed to discovery learning based on higher-order thinking skills. PBL has a positive impact on improving students' problem-solving skills, including identifying and understanding the problem, planning solutions, monitoring and analyzing progress, conducting experiments, and reviewing the problem-solving process (Dorimana *et al.,* 2022; Kök & Duman, 2023). PBL has a significant impact on improving student learning outcomes compared to traditional learning (Ahmad *et al.*, 2023; Nizaruddin *et al.*, 2019; Redlein & Lau, 2021; Sattarova *et al.*, 2023). Additionally, it can enhance knowledge and reasoning over time (Barth *et al.*, 2019).

Problem-based learning (PBL) has been shown to be effective in improving final exam scores, activating interest in learning, enhancing the ability to solve problems independently, enriching the knowledge structure system, and significantly training scientific thinking and teamwork (Song & Shen, 2023). Additionally, PBL has been found to have a major impact on improving students' science literacy (Parno *et al.,* 2020) and understanding of problem analysis (Bender *et al.,* 2023). Problem-based learning (PBL) has been shown to facilitate the development of knowledge, problem-solving skills, and self-regulation (Lonergan *et al.*, 2022). Additionally, PBL interventions have been found to be effective in teaching mathematical concepts to students (Boye & Agyei, 2023). PBL guides students in their learning process, including individual and group investigations, producing and presenting work, and assessing the problem-solving process (Suradika *et al.*, 2023).

Susanti *et al.* (2023) concluded that the application of PBL can enhance students' problem-solving and critical thinking skills in probability theory courses. The study proposed a five-step approach: (1) problem familiarization, (2) problem-solving organization, (3) individual and group investigations, (4) problem-solving presentation, and (5) analysis and evaluation of problem-solving procedures and solutions. Furthermore, the implementation of problem-based learning (PBL) has been shown to enhance graduates' problem-solving skills (Miliou *et al.*, 2022).

The enhancement of students' problem-solving skills is closely linked to the stages of the HOTS-based PBL process. This process stimulates students to think scientifically, reason critically, and constructively develop problem-solving skills. This can be accomplished by having students engage in HOTS problem exercises and posttest questions. Students can improve their physics problem-solving skills by focusing on the problem, describing relevant physics concepts, planning solutions, and implementing problem-solving strategies to evaluate magnetism problems.

A quantitative analysis was conducted to determine the improvement of students' physics problem-solving skills after PBL-HOTS was applied. The N-Gain test results of pretest and posttest scores between experimental and control groups are presented in Figure 1.

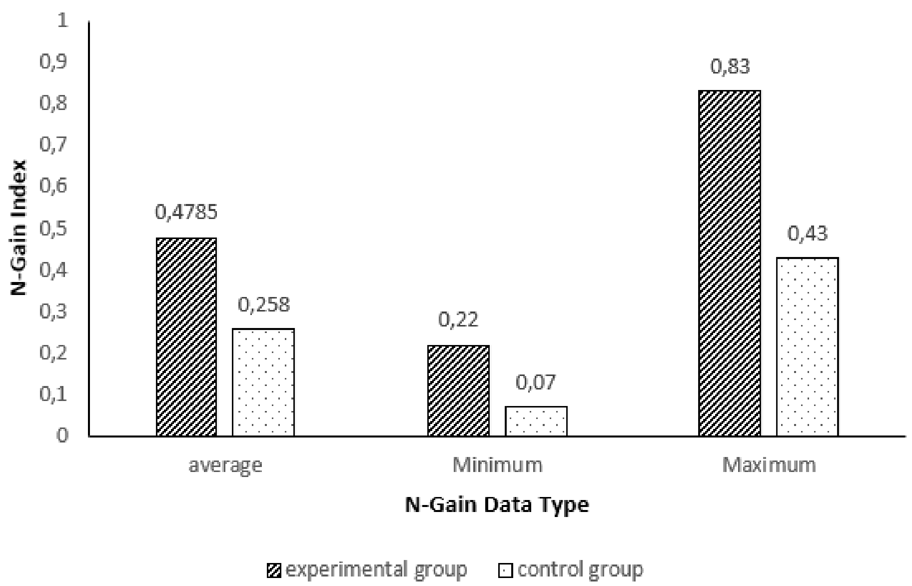

Figure 1. Comparison Diagram of N-Gain Test Results of Pretest and Posttest Values between Experimental Group and Control Group

According to Figure 1, both the experimental and control groups exhibited an increase in average pretest and posttest scores. The experimental group demonstrated a higher average N-Gain value, as well as minimum and maximum values, compared to the control group. Therefore, it can be concluded that the physics problem-solving skills of the experimental group, which applied PBL-HOTS, experienced a higher increase with moderate criteria than the control class, which applied PBL with low criteria. Research has shown that the application of PBL learning has significantly improved problem-solving skills (Ahdhianto *et al.*, 2020; Gumisirizah *et al.*, 2024; Kadir *et al.*, 2016; Valdez & Bungihan, 2019). PBL with scaffolding has also been found to have a positive impact on students' ability to express opinions and exchange ideas, as well as on the process of solving unstructured problems (Cho & Kim, 2020; Ernawati *et al.*, 2023). According to Irma *et al.* (2023), the integration of PBL with STREM can enhance students' scientific creativity, particularly through problem-solving processes.

Lidia *et al.* (2018) concluded that PBL assisted by modules has a positive effect on students' cognitive learning outcomes. The syntax of PBL can activate and organize students to solve learning problems, leading to improved cognitive learning outcomes. However, according to Damayanti *et al.* (2020), students typically score lower in the evaluation and creation aspects when identifying HOTS questions. Therefore, providing HOTS problem exercises in PBL has a positive impact on improving students' higher order thinking skills, particularly in physics problem solving. This is supported by Daryanti *et al.*'s (2019) research, which indicates that HOTS-oriented problem solving can enhance students' problem-solving abilities. HOTS-oriented Problem Solving is able to train and familiarize students to respond and solve problems skillfully, develop critical and creative thinking skills and train students to solve problems.

The article reviews and describes the process of qualitative data analysis based on interviews conducted by researchers and documentation of posttest sheets from both the experimental and control groups of students. Interview data from representatives of two samples of students from the experimental class and two students from the control class, who were randomly selected, were analyzed through the process of data reduction, presentation, and conclusion drawing. Qualitative interview data analysis was conducted to support quantitative data on students' physics problem-solving skills, according to Heller. The analysis included the following stages: focusing on the problem, elaborating on physics concepts, planning problem-solving solutions, implementing problem-solving plans, and evaluating problem-solving solutions. The conclusions drawn from the student interviews are presented in Table 2.

Table 2. Analysis of Student Interviews Results

Problem Solving Skills	Students			
	EG-1	**EG-2**	**CG-1**	**CG-2**
Problem 1	good	good	good	enough
Problem 2	enough	good	less	enough
Problem 3	enough	enough	enough	less
Problem 4	enough	good	enough	good
Problem 5	good	good	less	good
Problem 6	good	good	good	good
Problem 7	enough	enough	less	enough
Problem 8	good	good	good	poor
Problem 9	good	good	good	poor
Problem 10	good	poor	good	good
Conclusion	good	good	enough	enough

Based on Table 2, the analysis concluded that the majority of students in the experimental group (EG) were able to solve problems with good predicates as defined by Heller's criteria. In contrast, fewer students in the control group (CG) met the good criteria in solving problems related to magnetism. Therefore, it can be concluded that the problem-solving skills of the experimental group are better than those of the control group. Jailani *et al.* (2017) conducted research that supports the effectiveness of using HOTS in PBL to increase student involvement in problem-solving activities. This is achieved by encouraging students to analyze, evaluate, and create ideas, which enhances their critical thinking skills at a higher level. Consequently, students' ability to find solutions to problems is improved. However, students often make errors in presenting results and assessing solutions when solving physics problems, as noted by Fitroh *et al.* (2020). Therefore, it is important to provide appropriate treatment to help students think more critically and at a higher level when answering learning problems and presented problems. This will lead to better development of problem-solving skills.

A comprehensive analysis of the posttest documentation data from both the experimental and control classes was conducted to obtain an overview of the profile of physics problem-solving ability according to Heller's framework. Each question on the posttest documentation sheet was assigned a point value based on its alignment with the indicator. Specifically, questions that met the indicator received a value of 1 point, while those that did not meet the indicator received a value of 0 points. The results of the posttest documentation data analysis revealed a comparison of the indicators of physics problem-solving skills according to Heller between the experimental and control groups. The experimental group scored lower than the control group (84.69% vs. 87.19%) on the indicator of focusing the problem, which may be attributed to less careful students. In some cases, students may encounter difficulties when attempting to solve problems that cannot be directly addressed. This is particularly true when dealing with variables that are not explicitly stated but are necessary to describe the phenomenon being studied (Ellianawati *et al.*, 2021). Furthermore, the development of students' problem-solving abilities is closely linked to their understanding of how to approach problem-solving (Hourigan & Leavy, 2023). The factor of problem representation also impacts the ability of students to solve physics problems (Nugroho *et al.*, 2019). However, the problem-solving skills profile of the experimental class was superior to that of the control group on four other indicators. The percentage of indicators describing the physics concept is 70.94%, while the indicator for planning the solution is 87.81%, for implementing the problem-solving plan is 95.63%, and for evaluating the solution is 46.88%.

According to Heller's framework, indicators of problem-solving skills can be observed from the sample of students' posttest answers shown in Figure 2. The students demonstrated their ability to focus on the problem by identifying the magnetic poles in pictures (a) and (b). The students can describe the physics concept illustrated in figures (a) and (b). In figure (a), the north pole of the magnet is rubbed unidirectionally from point A to point B, resulting in point A becoming the north pole and point B becoming the south pole. In figure (b), an electric current flows clockwise in a coil wrapped around the metal from point P to point Q, resulting in point P becoming the north pole and point Q becoming the south pole. Students can plan a solution by bringing the two magnetic poles, the south pole at point B and the north pole at point P, closer together. They can then carry out the plan by providing a solution to the interaction of attraction between the two poles at points B and P. Finally, students can evaluate the solution by concluding that an interaction of attraction occurs between the south pole at point B and the north pole at point P.

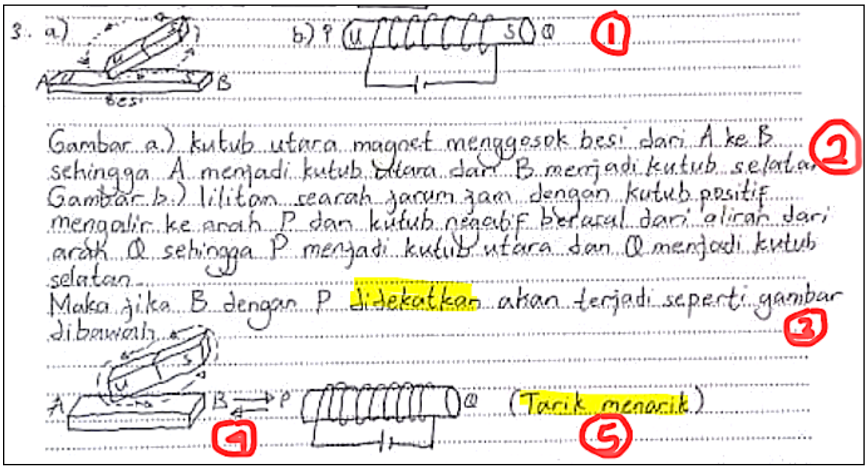

Figure 2. Posttest answers of students based on Heller's framework indicators for problem-solving skills.

The problem-solving skills that students demonstrate in their posttest answers cannot be attributed solely to their own abilities, as they may have been positively influenced by the Problem-Based Learning (PBL) steps applied during the learning process. Students are able to progress through constructive stages in building their problem-solving skills and formulating solutions. This aligns with Seyhan's (2016) research, which concluded that PBL has a greater impact on the perception of problem-solving and self-regulatory learning skills.Treepob *et al.*'s (2023) research also supports the idea that PBL management can enhance scientific problem-solving skills by following the steps of the problem-solving procedure. On the other hand, students' problem-solving skills depend mainly on their ability to plan and identify problems. The other stages of problem-solving, namely implementing the plan and checking back, are less dominant (Lurinda *et al.*, 2022). Therefore, problem-solving and decision-making skills can prepare individuals to face future challenges (Ubaidillah *et al.*, 2023).

Good reasoning skills will help students to solve problems well (Mulyati *et al.*, 2020). However, students' physics problem solving ability is not only related to understanding and reasoning, but also to mathematical problem solving. The problem solving stages are presented coherently and mathematically according to Heller's problem solving ability indicators from students' post-test responses, as shown in Figure 3. Students are able to focus the problem by gathering initial data information about the number of primary windings, secondary windings, and primary voltage in the transformer and describe it in terms of physics concepts in the form of symbols and numerical data. Students will be able to plan solutions by writing the calculation formula needed to find the value of the secondary voltage in the transformer. Students will be able to implement the solution plan by entering numerical data into the formula and performing calculations. In the final stage, students are able to evaluate the solution to the given problem by concluding the final results of the calculation of the value of the secondary voltage and concluding the type of transformer based on the results of the calculation analysis.

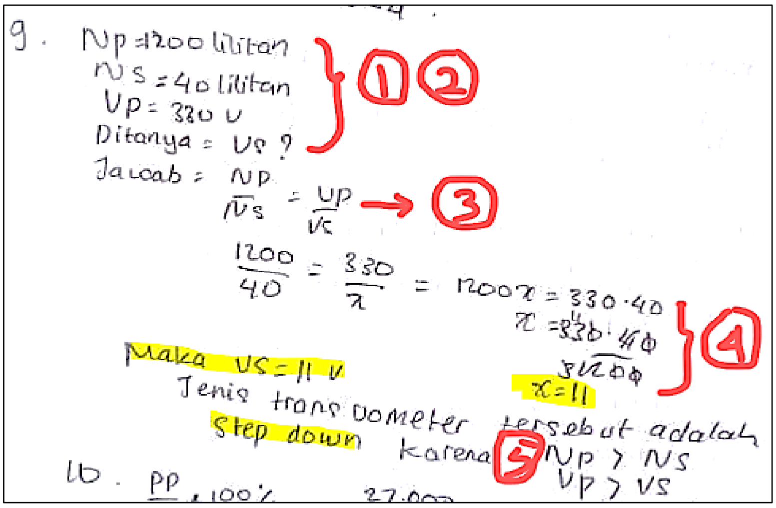

Figure 3. Posttest answers of students based on Heller's framework indicators for problem-solving skills

Semantic ability and mathematical logic ability play an important role in the problem solving process (Juliyanto *et al.*, 2021). However, most students in solving physics problems often use mathematical equations without analyzing, guessing the formulas used, and memorizing examples of problems that have been given to work on other problems (Winingsih *et al.*, 2023). Therefore, the ability to solve problems in mathematical form is important as part of efforts to develop higher-order thinking skills. Students with a good level of higher-order thinking skills are able to assemble an orderly pattern of answers mathematically from the initial stage of the question problem to the final conclusion of the answer, so that the solution to the problem becomes more concrete and easier. This is consistent with the findings of Abdullah *et al.* (2019), who concluded that students who successfully solve HOTS math problems produce the same process, starting with understanding, continuing with the planning stage, implementation, and ending with the final answer. Students with different levels of cognitive ability show different patterns of problem solving (Lasiani & Rusilowati, 2017). Rahayu *et al.* (2022) also concluded in their research that students' problem solving process involves symbolic and visual representations through the use of mathematical symbols, notations, numbers, and diagrams.

The experimental group given PBL-HOTS showed a higher percentage for the problem solving indicator compared to the control group given PBL. This result can be attributed to the students' familiarity with practicing problem solving on HOTS questions, which leads to the development of their higher order thinking skills, especially problem solving skills. Saraswati & Agustika's (2020) research emphasized that students who are less accustomed to working on HOTS type problems and lack of practice in designing problem solving steps result in low levels of thinking skills, especially problem solving skills. Good *et al.* (2024) also concluded that students will become proficient as physics problem solvers when they are accustomed to being faced with different types of context-rich problems. The conclusion that can be drawn from the percentages of the five indicators of physics problem solving according to Heller is that students tend to give direct answers to the post-test questions, especially the execution of the plan indicator. It is important for students to include all the necessary steps in their answers to show a complete understanding of the problem solving process. This is likely due to their habit of writing the final answer directly without including the steps of the initial process.

Conclusion

Based on the research results and discussion, the following conclusions were reached: (1) the physics problem solving skills of students given PBL-HOTS are better with a mean posttest score of 77.19 compared to the physics problem solving skills of students given PBL with a mean posttest score of 68. 31; (2) the increase in physics problem solving skills of students given PBL-HOTS is higher with an average N-gain of 0.4785 compared to the increase in physics problem solving skills of students given PBL with an average N-gain of 0.258; (3) the profile of students' physics problem solving skills according to Heller's framework after applying the PBL-HOTS learning model includes: (i) focusing on the problem by 84.69%; (ii) describing the physics concept by 70.94%; (iii) planning the solution by 87.81%; (iv) implementing the problem-solving plan by 95.63%; (v) evaluating the solution by 46.88%.

This study has limitations that affect the conclusions. Further research on PBL-HOTS should pay attention to improving several aspects, including: (i) observers are needed during the implementation of the research so that it is in accordance with the research plan and focus; (ii) interview data are collected from the entire research sample to strengthen the generalizability of posttest results; and (iii) posttest documentation data review is conducted by more than 1 investigator to maintain the level of research reliability.

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