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THE EFFECTIVENESS OF DYNAMIC PROBLEM-SOLVING STRATEGY AND INNOVATIVE ASSESSMENT TOOLS TO IMPROVE STUDENTS' HIGHER-ORDER THINKING SKILLS

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ABSTRACT

Education in Indonesia continues to face challenges in developing students' Higher-Order Thinking Skills (HOTS) to achieve Sustainable Development Goals (SDGs) 4 on quality education, which requires new strategies such as Dynamic Problem Solving (DPS) and innovative assessment tools to improve critical and analytical reasoning. This study aims to measure the DPS strategy and innovative assessment tools in improving students' HOTS in physics learning. This research method uses a quasi-experiment with a posttest-only control group design. This study involved 120 high school students from four regencies/cities in South Sulawesi, Indonesia. Data on the effectiveness of the DPS strategy were collected and analyzed using an independent t-test, and data on innovative assessment tools were collected and analyzed through validity and reliability tests. The results of the HOTS test of students after participating in physics learning using the DPS strategy and innovative assessment tools showed that the experimental group was better than the control group. This study concludes that implementing the DPS strategy and innovative assessment tools effectively improves high school students' HOTS through physics learning. This research impacts critical and analytical thinking in students to solve real problems. In addition, this research also contributes to being a reliable and robust new pedagogical approach in physics learning under the demands of 21st-century education.

Keywords: dynamic problem-solving; higher-order thinking skills; physics education; assessment tools

INTRODUCTION

Education aims to develop critical, creative, and innovative thinking skills. The fundamental goal of education is not only to gain knowledge but to become an important provider as a worker, society, and citizen (Alfaisal et al., 2024). According to the Law of the Republic of Indonesia No. 20 of 2003, education provides knowledge and prepares students to face challenges. The SDGs, particularly Goal 4: Quality Education, emphasize enhancing students' cognitive and problem-solving skills to ensure inclusive and equitable education (Bappenas, 2024). However, global and national assessments indicate that many students struggle to develop these essential skills. This aligns with global efforts to develop higher-order thinking skills (HOTS) to meet the needs of the 21st century. According to Liu et al. (2024). HOTS is a crucial skill for the country in the future. HOTS in the 21st century has become a basic need for every country through its educational and related institutions.

Higher-order thinking skills (HOTS), as described in the revised Bloom's taxonomy, include higher-order cognitive processes, such as

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analyzing, evaluating, and creating, which are essential for solving non-routine and complex problems (Aderson & Krathwohl, 2001; Misrom et al., 2020). However, Indonesia's ranking of 65th out of 81 countries in the 2022 PISA assessment, especially in science literacy, shows a gap in students' reasoning, application, and cognitive skills (OECD, 2015; Ismawati et al., 2023; Baltikian et al., 2024). Current science learning shows educators cannot help students achieve HOTS (Gembong et al., 2022). Nenohai et al. (2024) stated that there are still many misunderstandings about HOTS by educators. Educators' knowledge about HOTS is still low, especially in HOTS-based problem-solving skills and educators' abilities to measure students' HOTS.

In addition, the Trends in International Mathematics and Science Study (TIMSS) presented by Putranta and Supahar (2019) stated that the achievement of Indonesian students' physics learning outcomes is still low in the cognitive aspect, with a 27.6% deficit in conceptual understanding compared to OECD countries. It was further stated that the achievement of students' physics learning at the international level is still low, so it requires better conceptual understanding and creative thinking skills. Ineffective physics learning activities or inappropriate test instruments can cause this low achievement. Rachmawati et al. (2023) showed that 73.4% of physics educators had limited knowledge of HOTS implementation, and only 18.9% incorporated HOTS-based assessments in their classrooms. These results indicate the need for innovation in HOTS-oriented learning methods to effectively support students' cognitive development.

Physics, a branch of science focusing on problem-solving and critical reasoning, is an ideal platform to encourage HOTS (Haryani et al., 2021; Kwangmuang et al., 2021; Jamil et al., 2024). Physics examines knowledge about natural phenomena and becomes a means of thinking and reasoning to improve thinking skills and knowledge (Haryono et al., 2024). Through gradual thinking and reasoning exercises, students will find it easier to achieve HOTS-based problem-solving. As technology advances and life problems become more complex and dynamic, educators are increasingly challenged to plan appropriate and innovative learning according to the demands of the 21st century. Conventional learning is no longer attractive to students, and it is impossible to meet the demands of the 21st century, such as HOTS.

Conventional learning by educators has tended to limit student involvement in solving complex and dynamic problems (Jong, 2019; Maries & Singh, 2023). Complex and dynamic problems require dynamic solutions according to the circumstances that occur and change. This challenge can be overcome with a dynamic problem-solving (DPS) strategy, which integrates adaptive thinking and gradual solution refinement. DPS involves students continuously, from problem identification and hypothesis submission to solution testing with iterative feedback (Kleinman et al., 2022; Rojas et al., 2023). Students who learn with DPS have better HOTS and problem-solving results than conventional methods (Yurniwati & Soleh, 2020; Rahayu et al., 2022; Affandy et al., 2024). The application of DPS also encourages students to think profoundly and systematically when solving physics problems (Haris et al., 2024).

Learning with DPS can ensure that the problems faced by students are resolved and completed. This aligns with Miller et al. (2019), who state that, through DPS, one must use interpersonal skills to consider interconnected systems in solving problems. The DPS approach can not only impact solving students' problems in terms of knowledge but is also believed to positively contribute to overcoming environmental problems in real terms to ensure a sustainable quality of life (Mayona & Sutriadi, 2024). The DPS is a new problem-solving approach to educational research, but it has the suitability of learning structures with 21st-century learning to improve students' HOTS (Sepriyanti et al., 2022). Therefore, this study aims to fill this gap by investigating the effectiveness of DPS strategies and innovative assessment tools in enhancing students' problem-solving skills in physics education. Assessment tools adapted to learning approaches have good potential in predicting student achievement progress (Zulfiani et al., 2020). Thus, adapting innovative assessment tools is another novelty in this study.

This study targets findings as a theoretical framework of DPS learning strategies built and tested to address gaps in physics education, especially in improving students' HOTS. This study aims to successfully implement DPS strategies to improve students' HOTS through innovative assessments adapted to DPS learning tools. By focusing on literate learning and real problem-solving, this study aligns with contemporary education's goals: equipping students with the skills needed to face the complexities of the modern world (González-pérez & Ramírez-montoya, 2022; Nilimaa, 2023; AlAli, 2024). By addressing the empirical research gap in DPS and assessment integration, this study contributes to advancing 21st-century physics education. Additionally, this research aligns with global education policies (SDG 4) and national education reforms, offering a scalable instructional model for enhancing students' HOTS in Indonesia and beyond.

METHODS

This study is quasi-experimental with a posttest-only control group design (Bhattacherjee, 2012; Sugiyono, 2013). This study compares two groups of students based on the results of the HOTS-related post-test. The experimental group was taught using the DPS strategy, while the control group followed the conventional expository teaching method. Since no pretest was conducted, the evaluation only focused on the results after the intervention. The following is the design of this study.

R	X	O
R	-	O

Description:
X: Treatment with the application of the developed strategy
–: Treatment without the application of the developed strategy
O: Post-test (higher-order thinking skills)

The study population comprised high school students from four regencies/municipalities in South Sulawesi, Indonesia. To ensure representative sampling, two schools were selected from urban areas and two from regencies with the highest number of high schools. One hundred twenty students (30 per school) were selected using stratified random sampling (Creswell, 2009) to minimize selection bias and ensure proportional representation. To maintain consistency in pedagogical implementation, physics educators from the participating schools acted as facilitators after intensive training on the DPS methodology. The DPS strategy was implemented through structured learning modules, interactive discussions, and problem-solving tasks, aligning with 21st-century competency frameworks (González-salamanca et al., 2020; Affandy et al., 2024).

The primary research instrument was a validated HOTS-based assessment tool designed within the DPS framework to evaluate students' cognitive abilities in analyzing, evaluating, and creating solutions to complex physics problems (Aderson & Krathwohl, 2001). The instrument underwent rigorous validation through a two-phase process. First, expert reviews established content validity, ensuring alignment with HOTS indicators (Shrotryia & Dhanda, 2019; Li et al., 2024). Second, reliability was assessed using Cronbach's alpha (α), with a minimum acceptance threshold of 0.70 (Barati et al., 2019; Ekolu & Quainoo, 2019), while construct validity was verified through exploratory factor analysis (EFA) to ensure the instrument measured distinct cognitive domains (Baharum et al., 2023).

The research followed a three-phase data collection process to ensure methodological rigor and replicability. In the preparation phase, DPS-based learning modules were developed and validated, and physics educators were trained to ensure standardized implementation of the DPS strategy. During the implementation phase, students in the experimental group engaged in DPS learning activities, which involved problem identification, hypothesis formulation, iterative feedback, and solution refinement (Price et al., 2021), while students in the control group followed conventional learning with minimal problem-solving engagement. In the assessment phase, all students completed a HOTS post-test, and their responses were evaluated using a rubric-based scoring system to ensure consistency and objectivity in assessment.

Data analysis was conducted using SPSS (Version 28.0) (de Sa', 2007) following standard quantitative research protocols. Assumption testing included normality tests using Kolmogorov-Smirnov and Shapiro-Wilk tests to determine whether post-test scores followed a normal distribution, a prerequisite for parametric statistical analysis (Gosselin, 2024). Levene's test was applied to assess variance homogeneity across groups, ensuring the comparability of statistical tests (Gastwirth et al., 2009). For hypothesis testing, an independent t-test (parametric) or Mann-Whitney U test (non-parametric) was conducted to compare the mean HOTS scores of the experimental and control groups. A p-value of less than 0.05 was set as the significance threshold, indicating a statistically significant effect of the DPS strategy on HOTS improvement.

This methodological approach ensures the findings' validity, reliability, and robustness, thereby contributing empirical evidence on the effectiveness of the DPS strategy in fostering higher-order thinking skills. Moreover, the study provides a validated and practical assessment instrument for evaluating HOTS, supporting modern competency-based education practices aligned with the demands of 21st-century learning.

RESULTS AND DISCUSSION

The results of this study highlight the effectiveness of DPS strategies and assessment tools in improving students' HOTS through innovative assessments that are validated to measure HOTS achievement. The study began with developing several learning tools, including DPS learning strategies, teaching materials, student worksheets for question development, and formative assessment instruments based on DPS strategies. Experts validated these tools, and the analysis results are summarized in Tables 1, 2, and 3.

First, the validation results for the DPS Strategy show that all components of this strategy are considered valid, with Aiken's V value exceeding 0.75. The DPS strategy is proven to be effective in promoting group communication (V = 0.81), creating a fun learning environment (V = 0.94), supporting the implementation of teaching techniques (V = 0.81), and motivating students (V = 0.75). This validity indicates that the DPS strategy effectively supports activity-based learning that engages students actively, interactively, and communicatively. In addition, the problem-solving aspect, which is the core of the DPS strategy, is also considered valid (V = 0.81), indicating its suitability with modern pedagogical principles.

The reliability test for the DPS strategy produced a value of 0.82, indicating that this strategy can be applied consistently in various educational contexts. Likewise, the validation results for the Lesson Plan (teaching module) are designed to support the implementation of the DPS strategy. The components in the teaching module, such as learning activities, received the highest validation value (V = 0.94), indicating that the design of learning activities optimally supports students' engagement. In addition, components such as learning objective indicators, learning outcome formulations, and language use also received high validation values, each 0.88, indicating that the teaching module was designed systematically and clearly.

In line with these results, several studies published in "Sustainability" support that learning approaches focusing on problem-solving and metacognition effectively develop HOTS. Hamzah et al. (2022) emphasize the importance of metacognitive elements such as critical thinking and inquiry-based approaches, which align with the DPS strategy that encourages learners to reflect on the problem-solving process. Hanafiah and Suryani (2021) and Škėrienė and Jucevičienė (2020) add that problem-solving involving problem identification, fact analysis, and finding appropriate solutions is essential in developing HOTS. This study shows that DPS, which combines problem-solving with metacognitive elements, can improve students' critical and creative thinking skills, preparing them to face challenges in education and life. However, challenges such as varying students' motivation and time constraints remain in implementing this strategy. Ebel et al. (2020) and Sliwka et al. (2024) emphasize the importance of balancing a solid learning structure and adaptive flexibility to improve students' engagement and learning outcomes.

In line with this, the effectiveness of assessments under the DPS strategy and measurement of higher-order thinking skills (HOTS) achievement was carried out by synchronizing the DPS stages into an assessment consisting of three types of questions, which we call an innovative assessment. In addition, the instrument's alignment with the learning tool is essential. This is supported by Li et al. (2024), who highlight the importance of assessments aligned with the characteristics of the DPS strategy to stimulate students' skills in analysis, evaluation, and synthesis. In addition, Alt et al. (2023) and Pásztor-Kovács et al. (2023) discuss the potential of DPS assessments in evaluating students' problem-solving skills at the beginning of higher education. This study shows that assessments designed according to the DPS stages can improve students' critical and creative thinking skills.

This innovative assessment includes a test instrument with three questions: correct argument, information matching, and core solution. The alignment of the assessment with the characteristics of DPS, which emphasizes creating tiered solutions for fundamental to complex problems, helps stimulate HOTS (Nugrahnastiti & Kamaludin, 2024; Li, 2025). After the design, the innovative assessment was validated using the two-expert consensus technique with the Gregory analysis method. The results of the instrument validation showed a high level of agreement (R-value> 0.70). This finding aligns with the idea that well-validated instruments are essential for effective measurement in educational research (Creswell & Guetterman, 2018). Successful validation shows that the instrument is relevant and comprehensive in achieving the learning objectives set for this study, reinforcing the importance of expert input in developing educational instruments (Papadakis et al., 2020; Pan et al., 2021).

After the validation process, 15 questions were empirically tested to assess their reliability and validity. The results of the empirical validity test showed that the r-count for all questions was more significant than the r-table. In addition, the reliability analysis used Cronbach's alpha coefficient, while the validity assessment used the product-moment correlation coefficient. The findings from the reliability test showed that Cronbach's alpha coefficient was greater than 0.7, which confirmed the instrument's reliability. These results indicate that the instrument has a Cronbach's alpha coefficient greater than 0.7, confirming its reliability. In addition, the validity analysis confirmed that all items were statistically valid because the r-count value exceeded the r-table value. These findings reinforce the importance of using robust statistical methods to ensure the reliability and validity of educational assessments (Sürücü & Maslakci, 2020). In the educational context, valid and reliable assessments are essential to accurately measure student competencies and ensure educational interventions can effectively promote learning.

Evaluation of the learning steps in implementing the DPS strategy showed stability in the main steps: problem focus, analysis, planning, action, and evaluation. Overall, this implementation was categorized as "Well Implemented" because of the conformity of the learning steps with the DPS syntax embedded in the teaching module. This conformity ensures that the learning process is efficient and directed. Feedback from observers further supports the potential of DPS as an effective alternative to improve students' higher-order thinking skills, as emphasized by Kim et al. (2019). Figure 1 presents the average score of learning implementation.

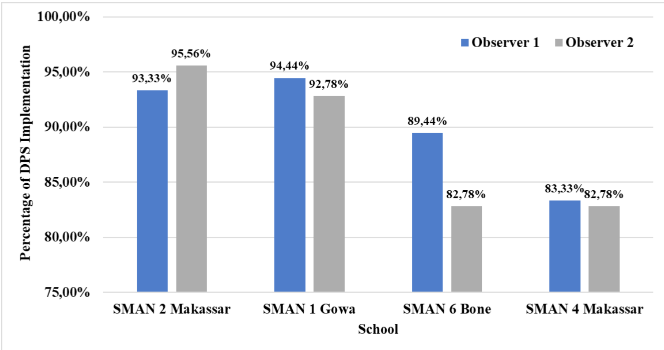

Figure 1. Average Percentage Score of Learning Activity Implementation

Figure 1 shows further observation results that the DPS strategy was successful at a high level in four schools: SMAN 2 Makassar (94.45%), SMAN 4 Makassar (83.06%), SMAN 1 Gowa (93.61%), and SMAN 6 Bone (86.11%). These results indicate that DPS effectively encourages critical and innovative thinking, especially in solving abstract and concrete problems. All early learning activities across schools were also categorized as successful, indicating that the structured learning steps within the DPS framework successfully engaged students and created meaningful learning experiences. This strategy improves students' problem-solving skills and is a structured and reliable approach in educational practice.

Table 1. Descriptive Analysis of Post-test Scores

School	Description	Control		Experimental	
		Statistic	Std. Error	Statistic	Std. Error
SMAN 1 Gowa	Mean	16.69	1.37	33.98	2.67
	95% Confidence Interval for Mean Lower bound	13.90		28.53	
	Upper bound	19.47		39.43	
	5% Trimmed Mean	16.56		33.27	
	Median	15.59		30.00	
	Variance	59.79		220.69	
	Std. Deviation	7.73		14.86	
	Minimum	5.30		6.67	
	Maximum	31.84		71.67	

SMAN 2 Makassar	Mean		13.45	1.77	24.62	2.04
	95% Confidence Interval for Mean	Lower bound	9.82		20.42	
		Upper bound	17.08		28.81	
	5% Trimmed Mean		12.65		24.31	
	Median		11.67		24.17	
	Variance		87.63		107.84	
	Std. Deviation		9.36		10.38	
	Minimum		1.67		6.67	
	Maximum		43.33		50.00	
SMAN 4 Makassar	Mean		5.47	1.17	23.41	1.70
	95% Confidence Interval for Mean	Lower bound	3.08		19.96	
		Upper bound	7.86		26.86	
	5% Trimmed Mean		4.61		23.54	
	Median		3.33		23.33	
	Variance		43.94		100.82	
	Std. Deviation		6.63		10.04	
	Minimum		.00		.00	
	Maximum		33.33		41.67	
SMAN 6 Bone	Mean		44.76	3.30	56.33	2.88
	95% Confidence Interval for Mean	Lower bound	38.04		50.41	
		Upper bound	51.48		62.25	
	5% Trimmed Mean		45.53		57.18	
	Median	48.67			61.40	
	Variance	371.07			232.93	
	Std. Deviation	19.26			15.26	
	Minimum	1.67			16.00	
	Maximum	73.89			77.50	

Implementing the DPS learning strategy in various schools significantly improved students' HOTS, as seen in Table 1. The experimental group was always superior to the control group. In SMAN 1 Gowa, the experimental group had an average score of 33.98, while the control group had 16.69. Likewise, in SMAN 2 Makassar and SMAN 4 Makassar, the experimental group had higher scores: 24.62 and 23.41. In SMAN 6 Bone, the experimental group achieved an average score of 56.33, while the control group was 44.76. These findings indicate that DPS effectively improves students' critical and analytical thinking in various schools (Rosário & Dias, 2024). Table 1 shows that the DPS strategy aligns with previous research findings that emphasize the role of structured problem-solving in developing critical thinking. Wu and Molnár (2022) identified that problem-solving strategies can improve cognitive abilities by encouraging analytical and systematic thinking, especially in abstract contexts. Analytical and systematic thinking helps students understand generally abstract physics content.

Furthermore, the normality test was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk methods. The normality test results showed varying levels of normality across schools and groups, as presented in Table 1. Thus, a varied and precise statistical analysis is needed to test the effectiveness of the DPS strategy.

Table 2. Result of Normality Analysis

School	Group	Kolmogorov-Smirnov			Shapiro-Wilk			Description
		Statistic	df.	Sig.	Statistic	df.	Sig.	
SMAN 1 Gowa	Control	.113	32	.200	.946	32	.113	Yes
	Experimental	.112	31	.200	.940	31	.080	Yes

SMAN 2 Makassar	Control	.183	28	.017	.885	28	.005	No
	Experimental	.086	26	.200	.978	26	.826	Yes
SMAN 4 Makassar	Control	.220	32	.000	.737	32	.000	No
	Experimental	.117	35	.200	.971	35	.474	Yes
SMAN 6 Bone	Control	.150	34	.051	.936	34	.046	Yes
	Experimental	.160	28	.047	.935	28	.083	Yes

In Table 2, at SMAN 1 Gowa, both the control and experimental groups showed normal distributions, with Kolmogorov-Smirnov significance values of 0.200 for both groups and Shapiro-Wilk values of 0.113 and 0.080, respectively. This distribution supports the use of parametric tests for further analysis. In contrast, at SMAN 2 Makassar, the control group data deviated significantly from normality (Sig. Kolmogorov-Smirnov = 0.017; Shapiro-Wilk = 0.005), which required the use of the non-parametric Mann-Whitney U test. Meanwhile, the experimental group data followed normality (Sig. Kolmogorov-Smirnov = 0.200; Shapiro-Wilk = 0.826), reflecting the DPS implementation's consistency. Similarly, in SMAN 4 Makassar, the experimental group data showed normality (Sig. Kolmogorov-Smirnov = 0.200; Shapiro-Wilk = 0.474), while the control group data did not (Sig. Kolmogorov-Smirnov = 0.000; Shapiro-Wilk = 0.000). Finally, in SMAN 6 Bone, both groups showed normal marginal distribution, with Kolmogorov-Smirnov significance values approaching the threshold (Sig. Kolmogorov-Smirnov = 0.047; Shapiro-Wilk = 0.083 for the experimental group). After the normality test results, the data were further processed using a t-test to assess the effectiveness of the DPS strategy.

Table 3. Parametric Statistical T-test

School	Levene's Test			t-test				
	F	F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.
SMAN 1 Gowa	Equal var. assumed	6.478	.013	-5.822	61	.000	-17.293	2.970
	Equal var. not assumed			-5.768	44.825	.000	-17.293	2.998
SMAN 6 Bone	Equal var. assumed	1.393	.243	-2.580	60	.012	-11.571	4.485
	Equal var. not assumed			-2.639	59.926	.011	-11.571	4.386

As shown in Table 3, in SMAN 1 Gowa, the t-test for equal variance yielded t(61) = -5.822, p 0.000<0.05, which confirmed a statistically significant difference between the experimental and control groups. This finding indicates a significant improvement in problem-solving skills facilitated by DPS. Similarly, SMAN 6 Bone showed a significant result of t(60) = -2.580, p = 0.012<0.05, although with a smaller mean difference than SMAN 1 Gowa, reflecting contextual variations in the implementation of DPS.

Table 4. Non-parametric Statistical T-test

School	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
SMAN 2 Makassar	140.500	546.500	-3.879	.000
SMAN 4 Makassar	84.500	612.500	-5.992	.000

Next, Table 4 presents the results of the Mann-Whitney U test for SMAN 2 Makassar and SMAN 4 Makassar. This analysis was applied because the data distribution in the control group was not normal. The results were highly significant, with Z = -3.879, p =0.000<0.05 in SMAN 2 Makassar and Z = -5.992, p =0.000<0.05 in SMAN 4 Makassar, which emphasized that the effectiveness of DPS is consistent across statistical conditions.

The empirical findings of this study provide strong support for the hypothesis that the DPS learning strategy significantly improves students' HOTS compared to the conventional expository teaching method. The significant differences observed between the experimental and control groups across schools highlight the effectiveness of DPS in developing critical and analytical thinking skills. These findings align with various literatures that emphasize the importance of active learning strategies in developing students' HOTS. Komatsu et al. (2021) and Martín-Alguacil and Avedillo (2024) stated that a student-centered active learning approach can improve performance in solving complex problems, thereby improving HOTS. Similarly, Akimov et al. (2023) and Patiño et al. (2023) stated that active learning and Education 4.0 initiatives are key in training students' complex thinking skills, including critical, systematic, and innovative thinking.

In addition, this study's significant results from parametric (t-test) and non-parametric (Mann-Whitney U) statistical analysis indicate that DPS is effective in various educational contexts and varying data distributions. This adaptability is vital for implementing learning strategies to improve students' HOTS in heterogeneous classroom settings. Thus, this study's findings impact students' HOTS and contribute significantly to improving the quality of physics learning. The use of innovative HOTS assessment tools also contributes to helping policymakers encourage learning strategies and evaluation tools that are more relevant to the demands of the 21st century.

Despite its success, the implementation of DPS still faces challenges, including variations in student motivation and deviations from the lesson plan due to time constraints. These limitations of the study still need to be improved in further research. Farrell and Brunton (2020) and Heilporn et al. (2021) support that balancing structured teaching strategies with flexibility can effectively increase engagement and learning outcomes. Overall, the findings of this study confirm that the DPS strategy contributes to physics education by enriching a strong pedagogical approach to improving students' HOTS in physics. In addition, these findings also contribute to alternative solutions in the form of interesting learning strategies in physics compared to conventional expository teaching methods.

CONCLUSION

This study concludes that implementing the dynamic problem-solving strategy and innovative assessment tools effectively improves high school students' HOTS through physics learning. This effectiveness can be achieved because the stages of the DPS strategy are implemented well and are at a high level of success. Valid and reliable innovative assessment tools in implementing the DPS strategy also contribute effectively to improving HOTS. The significance of this study lies in its contribution to fostering critical and analytical thinking among students, enabling them to address real-world problems in alignment with the Sustainable Development Goals (SDGs). Moreover, this research introduces a reliable and robust pedagogical approach that aligns with the demands of 21st-century physics education. To build upon these findings, future research could explore the long-term impact of this approach across different educational contexts and subject areas and investigate strategies for its broader implementation and scalability.

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